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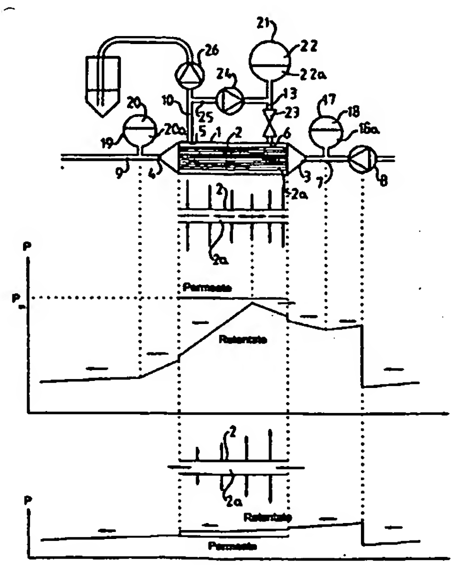
(54) Title: A METHOD OF CROSS-FLOW FILTRATION AND A CROSS-FLOW FILTRATION INSTALLATION



(57) Abstract:

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

A method of cross-flow filtration and a cross-flow filtration installation

The present invention relates to a method of cross-flow filtration utilizing a permeable membrane between the retentate and the permeate of the fluid for retaining particles present in said fluid in said retentate, the method comprising the steps of applying a first pressure differential between the retentate and the permeate for driving the fluid through the membrane in a filtering direction and causing the fluid to flow along the surface of the membrane facing the retentate during a filtering phase, and periodically backwashing the membrane by applying a second pressure differential between the permeate and the retentate during a period of time for driving the fluid back through the membrane in a backwashing direction during a backwashing phase.

In the following the invention is described in connection with a plurality of membranes configured as hollow fibres or tubular bodies arranged in modules, but it is not limited thereto. Furthermore, the invention is described generally in connection with microfiltration, but it may also be used for ultrafiltration or macrofiltration.

Cross-flow filtration with hollow fibre modules is often performed with a high linear axial velocity of the fluid to be filtered in the lumen of the fibres and/or along the outer surface of the fibres in order to keep the inner and outer surfaces free from fouling material by the cleansing effect of the high velocity fluid flow. Only very few methods are based upon a low linear axial velocity of fluid flow in the fibres, i.e. less than 2 m/s.

None of the known methods can prevent formation of a secondary layer of deposited particulate matter at the surface of the membrane. As the formation of this secondary layer is not only related to the properties which bind the layer strongly to the membrane surface, efforts have been made to avoid or remove a great part of the secondary layer by performing backflushing or backwashing of the membrane by periodically reversing the direction of fluid flow through the membrane.

In the method diclosed in EP 0 645 174 A1 the duration of the backflush pulses are from a few msec to 5 sec, the frequency of the backflush pulses is 1 pulse per sec to 1 pulse per 10 min, and the backflush counter pressure is 0.5 to 5 bar.

In the method disclosed in DK 166435 B1 the duration is 1 to 5 sec, the frequency is 1 to 10 pulses per min, and the transmembrane pressure during backflushing is 100-1000 kPa.

The axial linear fluid flow velocity in the fibre lumens is typically about 0.5 m/sec in the method according to EP 0 645 174, while it is higher in the method according to DK 166435. Actually, the latter is not explicitly disclosed, but has most probably been over 5 m/s.

According to EP 0 645 174, "The Backshock Technique" ref. Wenten (Ph.D.thesis 1994. Technical University of Denmark. Application of cross-flow microfiltration for processing industrial suspensions) a certain pressure should be applied for generation of the "backshock". Both in EP 0 645 174 and in the thesis the essential parameters and equipment are, however, not disclosed, hereunder the magnitude of the backflushed volume and the pressure conditions in the filtering system. Thus, it is not disclosed what actually takes place, i.e. how large a volume is backflushed how fast and whereto. Nor is there any useful specification of the operating conditions.

In ref. B.Czech, MBAA District Carribean, 34 Annual Convention 4/95 and in B.Czech, Filtrieren und Separieren, pp21 (1995), filtration results with beer based on the method of EP 0 645 174 have been published. The author´s conclusion was that economically feasible filtration between membrane cleaning could not be obtained.

The following beer filtration experiments based on the EP 0 645 174 method carried out in batch and continuous mode have been published.

The experiments in batch mode, which by definition includes a recirculation of retentate to the feed tank, are described by Wenten (Ph.D.thesis 1994. Technical University of Denmark. Application of cross-flow microfiltration for processing industrial suspensions). The parameters backflush time, backflush interval and the cross-flow velocity are described in the thesis and are according to the disclosure of the technique EP 0 645 174. Compressed air was used as backflush medium in the earlier experiments and permeate in the later ones. A drawing of the experimental installation with a newer version of the backflush system using permeate as backflush medium is published in the Danish Publication Ingeniøren no.16, 18.April 1997 "Chok hindrer filterstop". The filtration time between membrane cleaning was never more than 7 hours i.e. not an economically feasible method of filtration.

Experiments in continuous mode have been reported by B.Czech, MBAA District Carribean, 34 Annual Convention 4/95 and B.Czech, Filtrieren und Separieren (1995), pp.21. The backshock system and the parameters of the backflushing have not been described. It was only stated that the module has been "backwashed periodically".

The backflush system in the above batch experiments was a pulse damper arranged at a permeate inlet to the filter housing. The pulse damper contains a rubber membrane that is compressed using compressed air. When the rubber membrane is compressed, permeate is pressed through the permeate inlet into the filter housing and further back through the filter membrane. A valve at a permeate outlet of the housing is closed while backflushing, so that backflushing permeate does not simply escape through the permeate outlet. When the backflush has ended, the compressed air in the pulse damper is released, so the rubber membrane is pressed back by the differential pressure between the permeate and air, which now has atmospheric pressure.

Much effort has been exerted in recent years by different teams to lengthen the effective filtering time with this backshock technique between cleaning of the membrane, for instance chemically. This effort has so far been unsuccesful, and the general view is at present that the backshock technique is theoretically interesting, but not practically nor economically feasible.

The main object of the present invention is to provide a method of cross-flow filtration of the type in reference such that an economically viable method is obtained where the effective filtering time of the membranes and the installation as well as the energy requirements are such that the method can commercially compete with other known filtering methods.

According to the invention, this object is achieved by facilitating the flow of retentate relative to the membrane during said backwashing phase such that a substantial transport of retentate along and/or away from substantially all portions of the surface of the membrane facing the retentate is achieved during said backwashing phase.

During experiments carried out to achieve the object of the invention the inventors realized that as the backwashed volume in addition to the whole experimental set-up were not well defined, the pressure drops in the system during backwashing were also unknown. Thus, it was not known whether the membrane or parts thereof had been backwashed properly.

The inventors realized that if no substantial transport of retentate along and/or away from the retentate facing surface of the membrane takes place during backwashing at a given portion of said surface, the particles removed from said surface during backwashing would be deposited on and in said surface again when the flow through the membrane was reversed during the filtering phase.

By facilitating the flow of retentate along and/or away from the retentate facing surface it is achieved that the portions of retentate containing particles washed away from said surface, i.e. in principle permeate having been driven back through the membrane and thereby becoming retentate, either do not come into contact with said surface again during the subsequent filtration phase or are admixed with portions of retentate not containing such backwashed particles and thereby becoming diluted with "normal" retentate before coming into contact with said surface again.

Any portion of said retentate facing surface from and/or along which such a substantial transport of retentate does not take place during backwashing will quickly foul to a degree that no filtering flow can take place therethrough during the filtering phases. The problem will thereafter often build up in adjacent portions until the filtering flow decreases unacceptably in the entire membrane and the filtering pressure differential increases to unacceptable levels. Naturally, if such substantial flow away from and/or along said surface only is lacking at a small amount of the portions of the surface, such lack may be acceptable, but a corresponding fall in filtering efficiency will take place in any case.

An efficient transport of retentate during backwashing has also the important aspect of allowing the pressure conditions in the permeate and retentate to be such that the second pressure differential needed for efficient backwashing can be achieved in an effective manner without uncontrolled pressure oscillations and too high backwashing pressures leading to equipment failure or unacceptable vibrations.

In the preferred embodiment of the method according to the invention, the method comprises the further step of facilitating the flow of permeate relative to the membrane during said backwashing phase such that a substantial transport of permeate towards and/or along substantially all portions of the surface of the membrane facing the permeate is achieved during said backwashing phase.

Hereby it is achieved that the backwashing second pressure differential through the membrane is not reduced because of a pressure drop in the permeate because of a flow related pressure loss therein. Ideally, the flow rate of backwashed permeate per unit of area of the membrane should be the same for the entire membrane surface such that uniform conditions for backwashing for removal of the particulate layer and particles in the pores of the filter membrane are to hand. The configuration of the membrane and the flow paths of the permeate and the retentate during backwashing give rise to pressure losses in both the permeate and the retentate, and therefore it is advantageous that the flow of permeate rela-

tive to the permeate facing surface of the membrane be facilitated such that said flow of permeate is such that it corresponds to the flow of retentate and the pressures of the permeate and the retentate correspond to each other to the highest degree possible.

In the currently preferred embodiment of the method according to the invention, the membrane is arranged in a filter housing having a feed inlet, a retentate outlet, a permeate inlet and a permeate outlet or a combined permeate outlet and inlet. The housing may comprise more than one permeate inlet, permeate outlet, feed or retentate inlet and retentate outlet

The currently preferred method according to the invention furthermore comprises the further steps of providing permeate flow facilitating means for facilitating said flow of permeate and comprising a buffer container or hydrophore having a gas filled head space and a fluid filled space and arranged with the fluid filled space in fluid communication with said permeate inlet through a conduit with low flow resistance and in fluid communication with a constant flow pump, an open/close valve being arranged to open and close the fluid communication through said conduit between said fluid filled space and said permeate inlet, operating said constant flow pump continuously during both said filtering phase and said backwashing phase at a rate achieving a pumped volume during a filtering phase and the subsequent backwashing phase substantially equal to the desired backwashed volume of permeate in a backwashing phase, and opening said open/close valve during said backwashing phase and closing said open/close valve during said filtering phase, such that any increase in flow resistance through said membrane in the backwashing direction will entail an increase of the volume of said fluid filled space with a corresponding increase of the pressure in said gas filled head space.

Hereby, it is achieved that the backwash flow can be maintained relatively constant during a backwashing phase. Furthermore the backflush flow may hereby be maintained substantially constant over subsequent backwashing phases even though the membrane fouls and thereby increases the flow resistance therethrough. An automatic regulation of the backwash pressure may also be obtained by other means such as an increase in the head space pressure of the hydrophore by applying compressed air thereto in a manner controlled by the flow rate of the backwash such that a decrease in said flow rate entails supply of compressed air to said head space.

Alternatively, the method according to the invention may comprise the further steps of, providing permeate flow facilitating means for facilitating said flow of permeate and comprising a constant flow pump in interruptable fluid communication with said permeate inlet for pro-

viding the permeate flow in said backwashing direction, and, maintaining said constant flow pump in fluid communication with said permeate inlet during said backwashing phase at a rate achieving a pumped volume during said period of time substantially equal to the desired backwashed volume of permeate, interrupting said fluid communication between said constant flow pump and said permeate inlet during said filtering phase.

The backwash flow rate both during a backwash phase and over all such phases will hereby be relatively constant because of the constant backwash rate supplied by the constant flow pump.

The preferred embodiment of the method according to the invention comprises the further steps of providing a flow resistance means such as a valve and adapted for periodically reducing or stopping the flow of permeate through said permeate outlet, and activating said flow resistance means during said backwashing phase such that the flow of permeate through said permeate outlet is reduced or stopped. Hereby it is avoided that the backwash permeate flow is diverted from the desired transmembrane flow path thereof.

The second pressure differential or backwashing transmembrane pressure not only depends on the permeate pressure during backwashing but also on the retentate pressure and therefore it is advantageous that the method according to the invention further comprises the step of controlling the permeate pressure along the flow path of the permeate during said backwashing phase such that said permeate pressure is reduced substantially along said path, preferably reduced substantially corresponding to the reduction of the retentate pressure along the flow path of the retentate. Hereby, the backwashing transmembrane pressure may be controlled such that it becomes more constant over the extent of the membrane.

Preferably, one or more flow resistance bodies or spacers are arranged in said permeate flow path and/or a pump is arranged in fluid communication with said permeate inlet and outlet for pumping permeate from said permeate outlet to said permeate inlet during the backwashing phase.

Preferably, said second pressure differential is achieved by during said backwashing phase reducing the pressure of the retentate relative to the retentate pressure during said filtering phase and/or by during said backwashing phase increasing the pressure of the permeate relative to the permeate pressure during said filtering phase.

The currently preferred embodiment of the method according to the invention comprises the

further step of providing retentate flow facilitating means in fluid communication with said feed inlet and/or said retentate outlet for facilitating said flow of retentate from said feed inlet and/or said retentate outlet during said backwashing phase. Hereby the flow of retentate during backwashing away from and along the membrane is facilitated during backwashing.

Preferably, said retentate flow facilitating means comprise a first low flow resistance fluid conduit in fluid communication with said feed inlet and/or a second low flow resistance fluid conduit in fluid communication with said retentate outlet. Hereby the retentate conduits leading to and from the housing will entail a relatively low pressure loss in said retentate flowing out of the retentate outlet and/or said feed inlet and therefore a relatively free flow of retentate.

In the currently preferred embodiment of the method according to the invention, said retentate flow facilitating means comprise a first retentate reception means such as a buffer tank or a hydrophore in fluid communication with said feed inlet for receiving retentate from said feed inlet and/or a second retentate reception means such as a buffer tank or a hydrophore in fluid communication with said retentate outlet for receiving retentate from said retentate outlet during said backwashing phase. Hereby space is to hand for receiving the volume of retentate displaced by the backwashing flow such that the flow of retentate is effectively facilitated. Instead of such reception means, pumping means may be provided for pumping said retentate away thereby also facilitating the flow of retentate out the retentate outlet and/or the feed inlet of the housing.

Advantageously, the method according to the invention may comprise the further steps of providing an open/close valve between said first retentate reception means and said fluid inlet and/or between said second retentate reception means and said retentate outlet, closing said open/close valve or valves during said filtering phase, reducing the pressure in said first and/or second retentate reception means to a pressure substantially below the pressure of the retentate in said filtering phase, and opening said open/close valve or valves during said backwashing phase. Hereby the backwashing transmembrane pressure is achieved by "suction" from the said retentate reception means.

According to the invention, the membrane may be an asymmetric membrane, a reverse asymmetric membrane or a symmetric membrane.

The following defintions are to be applied:

A symmetric membrane is a membrane where the pore openings on the feed and permeate side are of the same size.

An asymmetric membrane has the larger pores on one side and the relatively smaller pores on the other.

A normal asymmetric membrane is a membrane with the smallest pores towards the feed side and the largest towards the permeate side.

A reverse asymmetric is a membrane where it is opposite. The largest pores are towards the feed side and the smallest towards the permeate side.

Preferably, the membrane has a mean pore size diameter between approx 0.2 micrometre and approx. 1.0 micrometre and has a permeability for water of more than approx. 5,000 l/h/m2/bar, more preferably more than 10,000l/h/m2/bar, further preferably more than approx. 15,000 l/h/m2/bar, further preferably more than approx. 20,000 l/h/m2/bar, further preferably more than approx. 25,000 l/h/m2/bar and most preferably more than approx. 30,000 l/h/m2/bar.

According to the invention, said second pressure differential between the permeate and the retentate at said feed inlet and said retentate outlet is maintained positive during at least 60% of said period of time, preferably at least 70%, further preferably at least 80%, most preferably at least 85% of said period of time. Hereby, a rational backwash procedure is obtained where the backwashing transmembrane pressure entails a transport of permeate in the backwashing direction during most of the backwashing phase at the feed inlet and the retentate outlet and thereby along most if not all the extent of the membrane.

When utilizing the method according to the invention for filtration of beer, preferably the time interval between consecutive backwashing phases is between approx. 0.5 sec and approx. 10 sec, said second pressure differential is between approx. 0.005 bar and approx. 6 bar , and the duration of each backwashing phase is between approx. 10 ms and approx. 5sec.

The present invention furthermore relates to a cross-flow filtration installation for removing particles from a fluid and comprising a permeable membrane having a retentate side and a permeate side and arranged in a housing having a feed inlet and a retentate outlet, the housing also being provided with a permeate outlet and a permeate inlet or a combined permeate outlet and inlet, first pressure generating means for generating a first pressure differential between the retentate side and the permeate side for driving the fluid through the

membrane in a filtering direction and causing the fluid to flow along the surface of the membrane facing the retentate during a filtering phase, second pressure generating means for periodically generating a second pressure differential between the permeate side and the retentate side during a period of time for driving the fluid back through the membrane in a backwashing direction during a backwashing phase.

The filtration installation according to the invention further comprises retentate flow facilitating means for facilitating the flow of retentate relative to the membrane during said backwashing phase such that a substantial transport of retentate along and/or away from substantially all portions of the surface of the membrane facing the retentate is achieved during said backwashing phase.

Preferably. the filtration installation according to the invention further comprises permeate flow facilitating means for facilitating the flow of permeate relative to the membrane during said backwashing phase such that a substantial transport of permeate towards and/or along substantially all portions of the surface of the membrane facing the permeate is achieved during said backwashing phase.

In the currently preferred embodiment of a filtration installation according to the invention said permeate flow facilitating means comprise a buffer container or hydrophore having a gas filled head space and a fluid filled space, a conduit with low flow resistance arranged for establishing fluid communication between said fluid filled space and said permeate inlet, a constant flow pump arranged in fluid communication with said conduit, and an open/close valve arranged in said conduit such as to open and close the fluid communication through said conduit between said fluid filled space and said permeate inlet and between said constant flow pump and said permeate inlet, said constant flow pump having a pumping rate at least sufficient for achieving a pumped volume during a filtering phase and the subsequent backwashing phase substantially equal to the desired backwashed volume of permeate during a backwashing phase.

Alternatively, said permeate flow facilitating means may comprise a constant flow pump in fluid communication with said permeate inlet and having a pumping rate at least sufficient for achieving a pumped volume during a backwashing phase substantially equal to the desired backwashed volume of permeate during said backwashing phase, and flow interrupting means such as a valve arranged for interrupting said fluid communication between said constant flow pump and said permeate inlet.

The currently preferred embodiment of a filtration installation according to the invention fur-

ther comprises a flow resistance means such as a valve arranged for periodically reducing or stopping the flow of permeate through said permeate outlet during said backwashing phase.

Advantageously, the filtration installation according to the invention may further comprise permeate pressure controlling means for controlling the permeate pressure along the flow path of the permeate between said permeate inlet and said permeat outlet during said backwashing phase such that said permeate pressure is reduced substantially along said path.

Preferably, said permeate pressure controlling means comprise one or more flow resistance bodies or spacers arranged in said permeate flow path and/or a pump arranged in fluid communication with said permeate inlet and outlet for pumping permeate from said permeate outlet to said permeate inlet during said backwashing phase.

The currently preferred embodiment of a filtration installation according to the invention comprises retentate flow facilitating means in fluid communication with said feed inlet and/or said retentate outlet for facilitating said flow of retentate from said feed inlet and/or said retentate outlet during said backwashing phase.

Preferably, said retentate flow facilitating means comprise a first low flow resistance fluid conduit in fluid communication with said feed inlet and/or a second low flow resistance fluid conduit in fluid communication with said retentate outlet.

In the currently preferred embodiment of a filtration installation according to the invention, said retentate flow facilitating means comprise a first retentate reception means such as a buffer tank or a hydrophore in fluid communication with said feed inlet for receiving retentate from said feed inlet and/or a second retentate reception means such as a buffer tank or a hydrophore in fluid communication with said retentate outlet for receiving retentate from said retentate outlet during said backwashing phase.

Alternatively, the filtration installation according to the invention may comprise an open/close valve between said first retentate reception means and said fluid inlet and/or between said second retentate reception means and said retentate outlet, and pressure reducing means such as a pump for reducing the pressure in said first and/or second retentate reception means to a pressure substantially below the pressure of the retentate during said filtering phase.

In the currently preferred embodiment of a filtration installation according to the invention, the membrane is configured as one or more tubular bodies, each tubular body having an

internal lumen adjacent an internal surface of the tubular body, and an exterior surface.

Said interior surface constitute said retentate side of the membrane and said exterior surface constitutes said permeate side of the membrane or, alternatively, said interior surface constitutes said permeate side of the membrane and said exterior surface constitutes said retentate side of the membrane.

In an alternative embodiment of a filtration installation according to the invention, said housing comprises a gas filled head space. Hereby, the flow facilitating means comprise said head space for either the permeate when filtration is inside/out and the retentate when filtration is outside/in.

Advantageously and for sanitary applications, said gas filled head space is separated from the remaining volume of said housing by a displaceable barrier such as a sheet of resilient material or a partition wall arranged displaceable in said housing in a direction transverse to the plane of said partition wall.

According to the invention, said housing may comprise a fluid filled space separated from the remaining volume of said housing by a displaceable barrier such as a sheet of resilient material or a partition wall arranged displaceable in said housing in a direction transverse to the plane of said partition wall, said fluid filled space communicating with the exterior of said housing by means of a fluid aparture preferably substituting said permeate inlet.

According to the invention the membrane may be an asymmetric membrane, a reverse asymmetric membrane or a symmetric membrane.

Preferably, the membrane has a mean pore size diameter between approx 0.2 micrometre and approx. 1.0 micrometre and has a permeability for water of more than approx. 5,000 l/h/m2/bar, more preferably more than 10,000l/h/m2/bar, further preferably more than approx. 15,000 l/h/m2/bar, further preferably more than approx. 20,000 l/h/m2/bar, further preferably more than approx. 25,000 l/h/m2/bar and most preferably more than approx. 30,000 l/h/m2/bar.

In another aspect, the present invention relates to a method of cross-flow filtration of a fluid utilizing a permeable membrane between the retentate and the permeate of the fluid for retaining particles present in said fluid in said retentate, the method comprising the steps of applying a first pressure differential between the retentate and the permeate for driving the fluid through the membrane in a filtering direction and causing the fluid to flow along the surface of the membrane facing the retentate during a filtering phase, periodically back-

washing the membrane by applying a second pressure differential between the permeate and the retentate during a period of time for driving the fluid back through the membrane in a backwashing direction during a backwashing phase.

In addition to the realization of the inventors discussed above, the inventors also realized in the course of their experiments that the pressure conditions in the permeate and retentate in the system in state of the art methods of the type indicated were not given much importance and consequently were not monitored to any substantial extent. The inventors realized that these pressure conditions were of great importance for obtaining economically viable results and therefore the method according to the invention further comprises the step of controlling the pressure on the retentate side and the permeate side of the membrane over time and/or along the filtering extent of the membrane both during the filtering phase and during the backwashing phase such that the desired flow characteristics are obtained along part of or the entire filtering extent of the membrane.

Although the feature of controlling said pressure conditions to a certain extent has common ground with the feature of facilitating the flow of retentate and permeate, this novel feature has independent importance for obtaining viable results with a method of the type in reference. In certain cases the flow of permeate and/or retentate should even be hindered or stopped so as to obtain the requisite pressure conditions in the system.

In the currently preferred embodiment of the method according to the invention, the membrane is arranged in a filter housing having a feed inlet, a retentate outlet, a permeate inlet and a permeate outlet or a combined permeate outlet and inlet, a pressure controlling means for controlling the fluid pressure during said backwashing phase such as a buffer container or a hydrophore and/or a constant pressure pump, preferably a low resistance constant pressure pump, being arranged at or near said permeate inlet for backwashing redelivery of previosuly removed permeate and at or near said feed inlet and preferably also at or near said retentate outlet.

Preferably, a low flow resistance fluid conduit is arranged between one or more of the pressure controlling means and the membrane.

The membrane may be an asymmetric membrane, a reverse asymmetric membrane or a symmetric membrane.

Preferably, the membrane has a mean pore size diameter between approx 0.2 micrometre and approx. 1.0 micrometre and has a permeability for water of more than approx. 5,000

The membrane may be an asymmetric membrane, a reverse asymmetric membrane or a symmetric membrane.

Preferably, the membrane has a mean pore size diameter between approx 0.2 micrometre and approx. 1.0 micrometre and has a permeability for water of more than approx. 5,000 l/h/m2/bar, more preferably more than approx.10,000l/h/m2/bar, further preferably more than approx. 15,000 l/h/m2/bar, further preferably more than approx. 20,000 l/h/m2/bar, further preferably more than approx. 25,000 l/h/m2/bar and further preferably more than approx. 30,000 l/h/m2/bar.

In a yet further aspect of the invention, the invention relates to a method of cross-flow filtration of a fluid utilizing a permeable membrane between the retentate and the permeate of the fluid for retaining particles present in said fluid in said retentate, the method comprising the steps of applying a first pressure differential between the retentate and the permeate for driving the fluid through the membrane in a filtering direction and causing the fluid to flow along the surface of the membrane facing the retentate during a filtering phase, periodically backwashing the membrane by applying a second pressure differential between the permeate and the retentate during a period of time for driving the fluid back through the membrane in a backwashing direction during a backwashing phase, and controlling said second pressure differential in accordance with the flow resistance through said membrane in the backwashing direction such that an increase in said flow resistance from one backwashing phase to the subsequent backwashing phase automatically entails a corresponding increase in said second pressure differential.

In the currently preferred embodiment of a method according to the invention, the membrane is arranged in a filter housing having a feed inlet, a retentate outlet, a permeate inlet and a permeate outlet or a combined permeate outlet and inlet, the method comprising the further steps of providing pressure controlling means for controlling the permeate pressure and comprising a buffer container or hydrophore having a gas filled head space and a fluid filled space and arranged with the fluid filled space in fluid communication with said permeate inlet and in fluid communication with a constant flow pump, an open/close valve being arranged to open and close the fluid communication between said fluid filled space and said permeate inlet, operating said constant flow pump continuously during both said filtering phase and said backwashing phase at a rate achieving a pumped volume during a filtering phase and the subsequent backwashing phase substantially equal to the desired backwashed volume of permeate in a backwashing phase, and opening said open/close valve during said backwashing phase and closing said open/close valve during said filtering

l/h/m2/bar, more preferably more than 10,000l/h/m2/bar, further preferably more than approx. 15,000 l/h/m2/bar, further preferably more than approx. 20,000 l/h/m2/bar, further preferably more than approx. 25,000 l/h/m2/bar and most preferably more than approx. 30,000 l/h/m2/bar.

According to the invention, said second pressure differential between the permeate and the retentate at said feed inlet and said permeate outlet is maintained positive during at least 60% of said period of time, preferably at least 70%, further preferably at least 80%, most preferably at least 85% of said period of time.

When the method according to the invention is utilized for filtration of beer, the time interval between consecutive backwashing phases is between approx. 0.5 sec and approx. 10 sec, said second pressure differential is between approx. 0.005 bar and approx. 6 bar , and the duration of each backwashing phase is between approx. 10 ms and approx. 5 sec.

In this aspect of the invention, the invention furthermore relates to a cross-flow filtration installation for removing particles from a fluid and comprising a permeable membrane having a retentate side and a permeate side and arranged in a housing having a feed inlet and a retentate outlet, the housing also being provided with a permeate outlet and a permeate inlet or a combined permeate outlet and inlet, a first conduit for supplying fluid to said feed inlet, a second conduit for receiving retentate from said retentate outlet, a third conduit for receiving permeate from the permeate outlet, and a fourth conduit for re-delivering permeate to said permeate inlet for backwashing, first pressure means for applying pressure in said first conduit and/or second pressure means for applying pressure in said second conduit and/or third pressure means for applying pressure in said third conduit and/or fourth pressure means for applying pressure in said fourth conduit, and pressure controlling means for controlling the pressure applied by one or more of said pressure means for controlling the pressure on the retentate side and the permeate side of the membrane over time and/or along the extent of the membrane both during a filtering phase and during a backwashing phase such that the desired flow characteristics of the retentate and permeate are obtained along part of or the entire extent of the membrane.

In the currently preferred embodiment of a filtration installation according to the invention one or more of said pressure means comprises a pressure buffer container or a hydrophore and/or a constant pressure pump, preferably a low resistance constant pressure pump, and one or more of said first, second, third and fourth conduits comprises a conduit with low flow resistance.

phase, such that any increase in said flow resistance through said membrane in the back-washing direction will entail an increase of the volume of said fluid filled space with a corresponding increase of the pressure in said gas filled head space.

Alternatively, the membrane is arranged in a filter housing having a feed inlet, a retentate outlet, a permeate inlet and a permeate outlet or a combined permeate outlet and inlet, the method comprising the further steps of providing pressure controlling means for controlling the permeate pressure and comprising a constant flow pump in interruptable fluid communication with said permeate inlet for providing the permeate flow in said backwashing direction, and maintaining said constant flow pump in fluid communication with said permeate inlet during said backwashing phase at a rate achieving a pumped volume during said period of time substantially equal to the desired backwashed volume of permeate, and interrupting said fluid communication between said constant flow pump and said permeate inlet during said filtering phase.

Preferably, the pressure controlling means further comprise a flow resistance means such as a valve and adapted for periodically reducing or stopping the flow of permeate through said permeate outlet, the method comprising the further steps of activating said flow resistance means during said period of time such that the flow of permeate through said permeate outlet is reduced or stopped.

The invention further relates to a cross-flow filtration installation for removing particles from a fluid and comprising a permeable membrane having a retentate side and a permeate side and arranged in a housing having a feed inlet and a retentate outlet, the housing also being provided with a permeate outlet and a permeate inlet or a combined permeate outlet and inlet, and pressure controlling means for controlling the permeate pressure and adapted for automatically increasing the pressure of the permeate at said permeate inlet when the flow rate into said permeate inlet decreases.

In the currently preferred embodiment of a filtration installation according to the invention, said pressure controlling means comprise a buffer container or hydrophore having a gas filled head space and a fluid filled space and arranged with the fluid filled space in fluid communication with said permeate inlet and in fluid communication with a constant flow pump, an open/close valve being arranged between said fluid filled space and said permeate inlet so as to open and close the fluid communication between said fluid filled space and said permeate inlet.

Alternatively, said pressure controlling means comprise a constant flow pump in fluid com-

munication with said permeate inlet for providing backwashing permeate flow into said permeate inlet.

Advantageously, the pressure controlling means further comprise a flow resistance means such as a valve adapted for periodically reducing or stopping the flow of permeate through said permeate outlet.

Finally, in a further aspect of the invention, the invention relates to a a cross-flow filter for removing particles from a liquid and comprising a housing having a feed inlet, a retentate outlet, a permeate outlet and a permeate inlet, one or more tubular members made of a filtration membrane and arranged in said housing, the housing having a gas filled head space and a fluid filled space

According to the invention, the fluid in said fluid filled space is in fluid communication with said feed inlet and said retentate outlet and the lumens of said tubular members are in fluid communication with said permeate inlet and said permeate outlet..

Alternatively, said fluid filled space is in communication with said permeate inlet and said permeate outlet and said permeate outlet and the lumens of said tubular members are in fluid communication with said feed inlet and said retentate outlet

In a sanitary version of the filter according to the invention, said gas filled head space is separated from the remaining volume of said housing by a displaceable barrier such as a sheet of resilient material or a partition wall arranged displaceable in said housing in a direction transverse to the plane of said partition wall.

In the following, the invention will be explained more in detail in connection with various embodiments of the method and the installation according to the invention shown solely by way of example in the drawings, where

Fig. 1 shows a diagrammatic view of the essential elements of the filtration installation utilized by Wenten ((Ph.D.thesis 1994. Technical University of Denmark. Application of cross-flow microfiltration for processing industrial suspensions) for experiments with beer as the fluid to be filtered, Fig. 1 also showing corresponding diagrams of the flow in a filter fibre and the permeate/retentate pressures during backwashing and during filtration shown below the installation diagram,

Fig. 2 shows the same as Fig. 1, but with different permeate/retentate pressures,

Figs. 3 and 4 show views similar to Figs.1 and 2 of the currently preferred embodiment of a filtering installation according to the invention,

Fig. 5. Shows a diagrammatic view of the installation shown in Figs. 3-4 indicating pressure sensors for measuring pressure at different points along the flow paths of retentate and permeate,

Figs. 6-9 show graphs of retentate and permeate pressure as well as transmembrane pressure during backwashing for different experiments with the filtering installation of Figs. 2-5 performed on ultra-filtrated destilled water,

Fig. 10 shows a graph illustrating the transmembrane pressure along a hollow fibre during backwashing,

Fig. 11 is a diagrammatic illustration of a filter module with a bundle of hollow fibres in a housing and a fibre.

Figs 12-15 show different situations of retained particles at the retentate facing surface of a filtering membrane

Figs. 16-28 show diagrammatic illustrations of different embodiments of a filtration installation according to the invention,

Fig. 29 shows experimental results for Comparative example no. IV,

Fig. 30 shows a diagram of the experimental rig used in Comparative example No. V,

Figs 31-33 show a diagram of the experimental rig used and the results obtained in Example No. I according to the new invention,

Figs 34-37 show a diagram of the experimental rig used and the results obtained in Example No. II according to the new invention,

Figs 38-40 show a diagram of the experimental rig used and the results obtained in Example No. III according to the new invention,

Figs 41-43 show a diagram of the experimental rig used and the results obtained in Example No. IV according to the new invention, and

Fig. 44 shows the results obtained in Example No. V according to the new invention.

Referring now to Figs. 1 and 2, a generally cylindrical filter housing 1 contains a bundle of parallel hollow fibres 2 of a permeable membrane material and comprises a feed or retentate inlet 3 and a retentate outlet 4, the inlet 3 and the outlet 4 being in fluid communication with lumens 2a of the hollow fibres 2. A cross sectional view of the bundle of fibres 2 in the housing 1 is shown in Fig. 11. The region between the fibres 2 and around the bundle contains permeate and is in fluid communication with a permeate outlet 5 and a permeate inlet 6 of the housing 1.

The feed inlet 3 communicates with a feed conduit 7 and a centrifugal pump 8 (constant pressure pump) and a not shown source of unfiltered beer or retentate while the retentate outlet communicates with a retentate conduit 9 leading to a not shown container for retentate or back to the pump 8. The permeate outlet 5 communicates with an open/close valve 11 and a container 12 for permeate or filtered beer. The permeate inlet 6 communicates with a backwashing conduit 13 and a backwashing pressure generator or backshock generator 14 having an internal rubber hose 15 surrounded by a space 16 filled with air and communicating with a not shown source of compressed air.

The operation of the filtration installation is performed according to the method disclosed in EP 0 645 174 A1, the subject matter hereof being incorporated herein by reference.

During the filtration phase unfiltered beer is fed into feed inlet 3 by the pump 8. A filtering pressure differential or filtering transmembrane pressure for generating permeate through the membrane of the fibres 2 is applied by the pump 8. Permeate or filtered beer is generated on the permeate side of the fibres 2 while particles in the unfiltered beer or retentate are retained on the inner surface and in the pores of the fibres as well as in the retentate, and the particles in the retentate are transported out of the filter with the cross-flow of the retentate axially through the lumens 2a from feed inlet 3 to retentate outlet 4 and through valve 11 to the container 12.

During the filtering phase the air pressure in the space 16 is atmospheric and the hose 15 is expanded to the shape indicated by dotted lines. Periodically a backwashing of the fibres 2 takes place by applying compressed air to the space 16 such that the hose 15 is compressed to the shape shown in full lines so that the permeate in the hose is partially pressed out through the conduit 13 into the housing 1 through the permeate inlet 6 thereby generating a backwashing pressure differential that drives the permeate back through the membrane walls of the fibres 2 into the retentate in the lumens 2a. The backwash flow of permeate washes the particles deposited on the inner surface of the fibres and in the pores or in-

terstices thereof into the retentate in the lumens 2a. The valve 11 is closed during the backwash phase so that the entire volume of permeate forced out of the hose 15 by the compressed air is forced through the fibre membranes.

The actual conditions of the experiments performed by Wenten with the installations shown in Figs. 1 and 2 are described in the following under the headings Comparative example No. I and No. II.

The inventors have performed a series of experiments and theoretical analyses with the purpose of investigating the possible reasons for the commercially unsuccesfull results of the backshock method applied by Wenten and other parties. In the following, the inventors' main assumptions as to the prevailing conditions during Wenten's experiments are discussed with reference to Figs. 1 and 2.

In the diagrammatic longitudinal sectional view of a fibre 2 shown immediately below the filter installation in Fig. 1, the vertical arrows indicate the direction and amount of fluid flow at different points along the fibers during backwashing. The backwash permeate crosses through the membrane in a volume ratio indicated in principle by the length of the vertical arrows. Near the inlet end of the fibres a filtrating flow is maintained for reasons discussed below.

The axial linear velocity in the lumen 2a is illustrated by the horizontal arrows and increases towards the retentate outlet 4 as permeate volume enters the lumen 2a.

Immediately below the longitudinal sectional view there is shown a diagram of the qualitative (i.e. distorted scale) pressure conditions at a certain point in time during the backwashing phase in the retentate and the permeate versus distance from the pump 8 to the end of the conduit 9. The horizontal arrows indicate the volume of the retentate flow and the direction thereof. The pressure Pm of the permeate is constant in the housing 1 while the maximum pressure in the retentate is higher than Pm and the retentate pressure varies because of retentate flow pressure losses.

As the retentate pressure is higher near the inlet end of the fibre, the retentate continues to flow through the membrane to the permeate side. The backwash flow rate increases towards the outlet end because of an increasing backwashing transmembrane pressure as the pemeate pressure is constant and the retentate pressure decreases.

In Fig. 2, the retentate pressure is lower than the maximum permeate pressure Pm and a flow equilibrium point is achieved at a distance from the inlet where the flow of retentate changes from being back towards the inlet to being forwards towards the outlet.

At the bottom of Figs. 1 and 2 the flow and pressure conditions during the filtering phase with clean fibres is illustrated in a manner similar to the diagrams thereabove.

The permeate pressure Pm in both situations (Fig. 1 and 2) is not constant during the backwashing phase because of the configuration of the backwash pressure generator and the relatively small volume thereof. Furthermore, pressure variations over time will take place because of pressure reflections such that the permeate and retentate pressure will oscillate and may give rise to large variations in the backwashing transmembrane pressure so that at times this pressure is positive and other times it is negative. Hereby backwashing only takes place during a certain percentage of the backwashing time period and filtration will take place the rest of the time.

The inventors believe that the above described conditions during backwashing at least partly are the reason for the rapid fouling of the membranes and the short times between necessary chemical cleaning of the fibres.

An explanation of why experiments according to the state of art technology did not generate a good performance is at least partly that the circulation pump pumps feed into the fibre during backwashing causing filtration at the inlet during backflushing. Only very high backwash pressures Pm (Fig.2) combined with the possibility that a certain volume of retentate can leave the filter inlet overriding the pump pressure will avoid this problem such that the whole fibre is backflushed. However, in such case the backwashing is not rational. The backwash fails at the inlet at least during the first part of the backwash until the feed flow has been stopped and reversed resulting in an overall very uneven backwashing. The pressure pattern during the first part of the backshock is shown in Fig.1. If the backflush pressure is moderate the situation in Fig.1 may be the case during the whole backflush period still resulting in a very uneven backflushing along the filter.

The phenomenen is more noticeable on long fibres (e.g. 1 m as in 1m^2 X-Flow modules) than on short fibres (0.5 m fibres as in 0.1 m^2 X-Flow modules). Suppose that the whole backwashing volume leaves through the retentate outlet, then, on short fibres for backflushing of e.g. 9 ml a backflush time of 22 ms is needed. A pressure drop resulting from traversing the membrane and from flowing along the fibre and leaving through the outlet has to be overcome. The longer the fibre, the bigger the pressure drop along the lu-

men of the fibre. Longer backwash times are necessary for pressing the same volume of permeate to the retentate side for the same pressure on the permeate side. Longer backwash times are indeed used on the longer fibres as the pressure applied to the permeate side can not be increased to very high values as the system only can withstand a certain pressure.

The increase in the backwash time is significant for rendering the problem from the circulation pump even larger. For instance a doubling of the backflush time causes the pump to pump double the volume of permeate into the fibres during backwashing, causing a fouling that is faster than with short fibres.

Referring now to Figs 3-5, the currently preferred embodiment of a filtering installation according to the invention is shown with the same elements as in Figs. 1-2 being indicated by the same references.

A hydrophore 17 having an air filled head space 18 and a retentate filled space 18a is arranged in communication with the conduit 7 between the centrifugal pump 8 and the filter housing inlet 3. A hydrophore 19 having an air filled head space 20 and a retentate filled space 20a is arranged in communication with the conduit 9.

A hydrophore 21 having an air filled head space 22 and a permeate filled space 22a is arranged in communication with the permeate inlet 6 over an open/close valve 23 in the conduit 13. A constant flow hose pump 24 is arranged in a conduit 25 in fluid communication with conduit 13 and with conduit 10. A constant flow hose pump 26 is arranged in conduit 10 between permeate outlet 5 and filtered beer container 12.

The portion of the conduit 7 between hydrophore 17 and inlet 3 is a large diameter, low flow resistance conduit as is the portion of conduit 9 between hydrophore 19 and outlet 4 such that flow of permeate to hydrophores 17 and 19 from the filter housing 1 is relatively unhindered.

Basically, backwashing is a movement of a certain permeate volume from the permeate stream to the retentate stream. For this movement to be effective, as the liquid is not compressible, it is important to create room in the retentate stream for this moved volume. This movement is achieved by applying a proper pressure for moving it and by assuring that the liquid can move to the desired space without much resistance. A lack of such space for receiving this backwashed volume and/or too much resistance will result in a pressure build-up and shaking of the installation.

The method according to the invention is thus implemented by intersecting the hydrophore 17 between the pump 8 and the filter feed inlet 3, the hydrophore 17 having a capacity sufficient for receiving the liquid coming from the pump 8 during backwashing and any volume of retentate that leaves the filter through the filter feed inlet 3. The hydrophore 19 placed after the retentate outlet 4 is intended for preventing a pressure build up by receiving that part of the backwashed volume that flows out through the retentate outlet 4 with low flow resistance during backwashing. Hereby the flow of retentate along and away from the fibre membrane retentate facing surface is facilitated during backwashing.

The hydrophore 21, the valve 23, the pump 24 and the conduit 25 substitute the backwash pressure generator 14 in Figs. 1 and 2. During filtration, the valve 23 is closed such that permeate is pumped into the hydrophore 21 by pump 24. The pump 24 operates at such a pumping rate that the volume of permeate backwashed during the backwashing phase minus the volume of retentate pumped by pump 24 during said backwashing phase is pumped into the hydrophore 21 during the filtering phase.

During backwashing, the valve 23 is open and the desired backwashed volume of permeate is provided by the hydrophore 21 and the pump 24. Hereby the permeate pressure during backwashing will be much more constant, particularly if the capacity of the hydrophore head space 22 relative to the capacity of the permeate filled space 22a is dimensioned correctly. The pressure variations in the installation during backwashing will also be reduced hereby.

The constant flow pump 26 functions as a permeate flow restricting means to avoid that much backwash permeate is pumped into the container 12 and not through the fibre membrane.

The backwash generating arrangement according to the invention shown in Figs. 3-5 furthermore provides an automatic pressure controlling means for controlling the permeate pressure in accordance with the increasing flow resistance through the fibre membrane owing to gradually increased fouling of said membrane such that the backwash volume is maintained substantially constant during all backwashing phases even though the membranes become gradually more fouled.

The volume of the retentate filled space 22a will gradually increase while the volume of the air filled head space will correspondingly decrease when the flow resistance through the membrane increases because the constant flow pump 24 will pump at the same rate independent of said increase in flow resistance. Hereby the pressure of the air in the head space 22 will increase correspondingly so as to overcome the increased flow resistance.

In other words, the backwash system of Figs 3-5 is of a pumped type which ensures that a constant volume is backflushed independently of the resistance in the other parts of the system, but the invention is not limited to the use of this type of backwash system.

The pumped backwash system is of the principle described in the following. The constant flow pump 24 pumps permeate into the partly gas filled hydrophore 21. The pump pumps both during filtration and during backwash. The hydrophore 21 is connected to the filter housing 1 through a valve 23 which is closed during filtration and open during backwash. As the hydrophore 21 is filled the pressure will rise. When backwashing, the pressure in the hydrophore 21 will push permeate back through the membrane. If the pressure in the hydrophore is not sufficient to push all the required volume back in the available backwashing time; the pressure will not be completely released. This will lead to pressure buildup that will gradually increase the backwashed volume, until an amount equal to what is received during a complete cycle is pushed back. When the backwashed volume is equal to the volume pumped during a complete filtering/backwashing cycle, the pressure will no longer increase. This means that the setup acts as an integral controller.

Using hydrophores it is possible to establish a backwashing transmembrane pressure in the total length of the fibres 2 during backwashing and to backwash a large enough volume in a short enough time frequently enough. A large pressure is built up in the very first moment of the backwash in the whole filtration system. What thereafter happens in detail is explained below in connection with the water experiments. In fig. 3 and 4 the backwash is absorbed by the hydrophores 17 and 19 to different degrees along the length of the fibres.

The capacity of the simple buffers shown in fig. 3 and 4 for absorbing the backwashed volume and pumped feed during backwashing depends on the amount of gas and the volume of the headspaces 18 and 20 of the hydrophores. If the headspace is too small, the capacity is also too small. If there is a membrane inside which separates the gas and liquid phase, this may set a maximum on the volume that the buffers can contain.

The hydrophores should, apart from having enough capacity to hold the incoming volumes, also have enough capacity to absorb the dynamic energy from the backwash flush. Dynamic energy is associated with the velocity with which the volume travels from the permeate stream to the retentate stream and in the connecting conduits. Thus, in order for this dynamic energy to dissipate in a controlled manner, the hydrophores 17 and 19 should also be able to absorb the energy from the backwash quickly enough. A smaller backwash duration (the backflush volume is the same) needs a higher damping capacity.

The backwash volume has to be buffered at the retentate stream mainly to avoid an increase of pressure in the system. The idea is as described above to mount hydrophores at one end, preferably at the front or in both ends of the filter. With a hydrophore at both ends it becomes flexible to control the degree to which the backwashed volume should flow in the two directions, ie. towards the inlet and towards the outlet. One can simply install a control system on these two hydrophores. In addition, one can install a device to create a pressure drop on the permeate side, i.e. by installing a spacer or insert or by recirculation of permeate from permeate outlet to permeate inlet with a pump, or a combination thereof as described more in detail in the following.

It should be noted that the hydrophore 17 can be left out if the pump 8 is a non-positive pump e.g. a centrifugal pump with a low pump height and a flat pumping characteristic, conduit 7 is a large diameter, low resistance conduit leading past pump 8 to a nearby buffer container, for instance a storage tank for retentate. In this case, during backwashing the flow rate of the pump 8 will decrease or even reverse. In the latter case a significant part of the backwashed volume of retentate leaves through the filter feed inlet 3 and continues through the pump 8 and further upstream to the buffer container without a substantial pressure build-up. This will be the case in a batch configuration, where the pipes are short enough and of a large enough inner diameter. Furthermore, it is assumed that the pump regains its performance with no significant delay. The solution is not feasible in continuous mode of standard plant design but it is in batch mode but only for a proper choice of membrane configuration and system configuration (0.5 m long filters of i.d. 1.5 mm-fibres working at 100 $l/h/m^2$ for 30 h) but it is apparently not of commercial interest. See examples IV and V according to the new invention in the following.

In continuous mode filtration (best on filters with relatively large inner diameter , I.D, (e.g. 3mm)) it is theoretically possible to avoid use of buffer containers, but then the conduits to storage tanks both before and after the filter should not give rise to any significant pressure drop during backwashing. The conduits to the storage tanks should then be short and have a large I.D., which will be much larger than those typically applied to ensure proper cleaning with minimal energy input. This is perhaps not of commercial interest either.

Below the view of the installation in Fig. 3, the vertical arrows indicate the amount of backwashed volume backwashed over the membrane at different points along the fibres. The backwash volume crosses the membrane in a volume ratio indicated by the vertical arrows. The axial linear velocity in the fibre increases as permeate volume enters the lumen of the fibre.

Fig.3 also shows a diagram of the qualitative pressure drop versus distance along the fibres and in the conduits 7 and 9 (horizontal arrows indicate the volume flow direction). As the backwash volume is allowed to move without significant pressure build-up, the maximum pressure, P_m, on the permeate side is also smaller than in Fig.2. Retentate is moved in the two directions out of the filter. The ratio of volume moved in the two directions is determined by the damping or buffering capacity of the two hydrophores 17 and 19.

Fig.4 shows the situation where the backwash volume just hinders the feed from entering the filter inlet. In this situation the whole backwash volume moves towards the filter outlet 4.

Fig. 5 shows the filtration installation of Figs. 3 and 4 with pressure sensors P arranged at interesting points along the flow of permeate and retentate. Pbf measures pressure in hydrophore 17, Pin retentate pressure at feed inlet 3, Pbs permeate pressure at permeate inlet 6 (backwash or backshock pressure), P1, P2 and P3 permeate pressure near inlet, middle and outlet of the filter housing 1, Pout retentate pressure after outlet 4 and Pbaf pressure in hydrophore 19.

Four experiments carried out by the inventors with a filtration installation as shown in Fig. 5 with ultra-filtered distilled water and later proven useful on centrifuged, unstabilised, unfiltered Carlsberg pilsner 14.5 will be discussed in the following in relation to Figs. 6-9. In these experiments with water the filtration system was equipped with a hollow fibre module with a surface filtration area of 0.93 m^2. Its housing had a permeate inlet with an opening for inlet of backwash volume with a cross-section area of 9.6 cm^2. The backwash was carried out with valve 23 being programmed with an opening time of 100 ms every 3 s. The backwashed volume was 150 ml.

The feed rate was 750 l/h and the permeate flow rate was 400 l/h. The membrane module used was supplied by the Dutch company X-flow (type MF10 M2 RA) with fibres with an inner diameter of 1.5 mm and max. pore size 1.0 μm . The pressures were monitored every 0.5 ms at the points indicated in Fig. 5.

The first experiment corresponding to Fig. 6 was carried out with the hydrophores 17 and 19 having essentially no buffering capacity thus approximating to a certain extent the Wenten experimental system of Figs. 1 and 2 with the difference that the backwashing pressure is much more constant over the backwash period. The pressure curves in Fig. 6 show that the movement of the backwash volume, due to the resistance against being moved because of no receiving space in the hydrophores, results in an oscillation of the the pressures and of the transmembrane pressure (backwashing pressure differential) at inlet (Pin minus P1) and

outlet (Pout minus P3). An error of up to 15 mbar is obtained on the calculated TMPin and TMOout during backwashing due to that Pin and Pout are measured outside the fibres on the retentate side. The error is so small that this has not been taken into account and is not needed taken into account in the discussion of the results below.

A negative transmembrane pressure will drive permeate in the backwashing direction, i.e. a positive backwashing pressure differential, while a positive transmembrane pressure will drive retentate in a filtering direction, i.e a positive filtering pressure differential.

The graph showing TMPin and TMPout shows that backwashing takes place during the first 20-30ms efter backwash start whereafter filtration takes place during 10-15ms and so on. A positive backwashing pressure differential (negative TMP in the graph) is to hand approx. 65% of the backwashing period at the inlet (TMPin) and approx. 19% at the outlet (TMPout) The inventors believe that the results shown here are better than any results that could be obtained with the same pressure measuring points in the Wenten experiments because of a more constant Pbs towards the end of the backwash period on acount of the improved backwash pressure generating system used.

The filtration effect or forward flush (contrary to backwash) should be avoided since that will have a contrary effect provoking a fast fouling of the membrane and an inefficient back-washing.

In the next experiment corresponding to Fig. 7 with a max buffer capacity of the hydrophores 17 and 19 of 100ml the generation of the forward flush is still observed albeit with certain differences. A positive backwashing pressure differential (negative TMP in the graph) is to hand approx. 57% of the backwashing period at the inlet (TMPin) and approx.86% at the outlet (TMPout).

In the next experiment corresponding to Fig. 8 with a max buffer effect of 200ml in hydrophores 17 and 19, the forward flush is avoided entirely from approx 10ms after the start of backwashing. With this max. buffer capacity of 200 ml the backwash volume is received in the buffers 17 and 19 with a negative and uniform TMP along the membrane in the entire backflushing time. A positive backwashing pressure differential (negative TMP in the graph) is to hand approx. 97% of the backwashing period at the inlet (TMPin) and approx. 85% at the outlet (TMPout)

In the next experiment corresponding to Fig. 9 with a max buffer effect of 100ml in the outlet hydrophore 19 and 200ml in the inlet hydrophore 17, forward flush is obtained at the outlet,

while the TMPin curve is very similar to the one in Fig. 8. A positive backwashing pressure differential (negative TMP in the graph) is to hand approx. 97% of the backwashing period at the inlet (TMPin) and approx. 84% at the outlet (TMPout) It can therefore be seen that the pressure results depend on the capacity of the hydrophore, i.e. the ability to receive retentate. Using different capacities in the hydrophores, the backwash pattern can be controlled. Instead of hydrophores, open or closed vessels can be used and they will just function as extra feed reservoirs at the same time. In fact, any means for facilitating transport of retentate out of the filter housing feed inlet and/or out of the retentate outlet will give similar results albeit with different installation costs and operating costs.

For all the above and below non-limitative examples of the invention, a low pressure drop inside a fibre, ΔP_L, should be aimed for as the backwash then becomes more uniform. In a fibre with a water permeability, WP, of 17500 l/hm^{2}bar, I.D. of 1.5 mm, as seen from the calculations in table 2 below, ΔP_L is in many cases (beer filtration) large compared to TMP_{BF}, where TMP_{BF} is the transmembrane pressure during backwashing. The reason for this is that a high throughput is desired which calls for a very short backwashing time, BF-time.

Fig. 10. is an illustration of the benefit of dividing the retentate flow properly in both directions in a hollow fibre as can be achieved by the method according to the invention. In this case 50 % of the backwash or backflush volume, BF-volume, is backwashed backward in the feed direction, such that the backwashing becomes more uniform. The benefit of dividing the flow is also illustrated by the values in table 1 below. The total backwash volume needed is much smaller if the backwash is uniform. This has a large impact on the filtration performance.

ΔP_L as a function of the position inside the fibres can be calculated using the Hagen Poisuille equation. Fig.10 indicates the qualitative ΔP_L versus position inside a fibre assuming I) that the backwashed volume flow is only out of the fibre one way (through the retentate outlet) or II) that the volume flow is divided into two halves that flow in each direction out of the fibre.

BF-flow pattern	Filter Area	Filter length	No. of Fibres	BFtime	Bf-Vol	CV_{outl} BF	ΔP_L	Re	TMP_{BF}
	m2	m		ms	ml	m/s	bar		bar
Not divided	1	1	230	22	90	10	4.98	4284	2.95
BF-flow	0.1	0.5	50	22	9	4.6	1.14	1971	2.95
Divided (50%)	1	1	230	22	90	5.0	1.24	2142	2.95
BF-flow	0.1	0.5	50	22	9	2.3	0.29	985	2.95

Table 1.

ΔP_L, Re (Reynold´s number) and TMP_{BF} for the the extreme cases: a) 100 % of the backwashed volume, BF-vol, leaves through one of the ends of the fibre and b) 50 % leaves through each end of the fibre. CV_{outl}BF is the cross-flow velocity in the fibre at the outlet of the fibre. The calculations are based on the following assumptions.

- Feed is pumped in through the inlet immidiately after the backwash with a pump which works with 100 % of the efficiency from before the backwash
- No feed is pumped in during backwashing.
- I.D. 1.5 mm, outer diameter, O.D., 2.35 mm,
- viscosity of beer: 3.5 E-6 m^2/s
- beer permeability: 5000 l/h/m^2/bar or water permeability, WP, 17500 l/h/m^2/bar
- density of beer: 1 g/cm^3
- CV, cross-flow velocity at inlet of fiber: 0.57 m/s
- Not divided BF-flow means that no BF-volume leaves through the inlet of the fibre towards the pump.

– Divided BF-Flow means that 50% of the BF-volume leaves through the inlet of the fibre towards the pump.

– Backwash interval is 1.5 s.

I.D. plays a role analogous with the role of WP. Fibres with the same WP will have a larger ΔP_L the smaller the I.D. This becomes clear from looking at the Hagen Poisuille equation:

$$\Delta P_L = CV \cdot \frac{8 \cdot \eta \cdot \rho \cdot 4}{(d/2)^2}$$

CV cross-flow velocity in fiber
η viscosity of fluid
ρ density of fluid
d I.D. of fiber

By application of backwashing to a hollow fibre module (see Fig. 11 where a cross section of a fibre filter housing 1 is shown at right with an enlarged illustration of a fibre 2 at left), where the filtration is performed inside/out (a non-limitative example), the backwash volume is pushed back (see Fig. 12).

In Figs. 12-15 the fibre feed inlet is at the right and the fibre retentate outlet is at the left Fig. 12 shows the situation between 0.00 sec and 0.05 sec from the start of the backwash period, Fig. 13 between 0.05 sec and 0.10 sec, Fig. 14 between 0.10 sec and 0.20 sec where filtration again takes place, and Fig. 15 between 0.20 also with filtration taking place, the backwash period being 0.10 sec. The black dots 30 indicate retained particles on and in the fibre membrane inner surface 31 (retentate facing surface). The number of dots 30 is only a qualitative indication of the amount of retained particles. The arrows indicate the volume flows.

The volume elements with retained particles push back a corresponding pore volume bounding the membrane inner side (in the Figures towards the retentate outlet). Here it is mixed with the lumen phase with fresh feed and travels towards the retentate outlet, such that new volume elements from the lumen phase upstream can be moved forward (Fig. 13). The volume elements of mixed volumes are thereupon partly concentrated at the pores and partly filtered into permeate by the following filtration (Figs. 14 and 15). The new concentrated volume elements are thereupon pushed back during the following backwash. The stronger the backwash volume is mixed with the lumen phase the lower one can choose the

exchange rate of retentate in the fibres, i.e. the cross-flow velocity. It is assumed that the concentration factor has a negative influence on the filterability.

The maximum effect of cross-flow filtration is achieved when the lumen of the filter is emptied away from the feed direction fully during each backwash before the next filtration period starts. The exchange rate of retentate obtained by the cross-flow then becomes immaterial.

If the lumen of the filter is emptied away from the feed direction but not fully in each backwash before the next filtration period starts, two variables must be sufficiently large. These are the exchange rate of retentate during the filtration period and the mixing immediately after the backflush of backflushed pore volume containing the retained particles with lumen volume.

Thus, in order to obtain an effective backwashing it is important that the membrane pores and membrane surface are clean of retained particles. To achieve this condition it is important to have an effective mixing of the backwashed volume with the retentate stream especially at the membrane surface. The amount of backwashed volume needed may in general depend on the concentration of retained particles in the feed, as it has been observed for beer. The concentration of retained particles in the lumen phase is directly related to the exchange rate of the retentate in the membrane.

The volume velocity for backwashing should be kept as high as possible in order to shorten the backwash time and thereby to maximise the total filtration time. A certain minimum volume has be to be applied, see below. At the same time the negative TMP during backwash must not be too high otherwise the fibres will break. Moreover, the pressure on the retentate side must not be too high compared to the pressure on the permeate side otherwise the filtration system will vibrate.

Net accumulation of retained material is avoided/minimised by choosing the exchange rate, backwash volume, and mixing, optimally.

With reverse asymmetric membranes the complex of problems is another. Here both filtration and up-concentration take place in the pores. The cross-flow velocity has no independent importance for removal of particles from the pores. In this case it is therefore important to obtain a sufficient cleaning of the pores by the backwash in order to achieve the maximum filtration effect in the following filtration period provided the concentration factor has a negative influence on the filterability of the fluid. However, the lumen fluid elements should still be exchanged sufficiently rapidly.

In order to obtain a sufficient backwash cleaning after each filtration period, a certain minimum volume defined by the medium to be filtered should be used. This has been observed in filtration runs on beer. The existence of a certain minimum volume may also be the case for other membranes than reverse asymmetric membranes.

In addition to that a certain minimum volume value should be used, the permeate flow (which depends on TMP) should be controlled very precisely. Changes of TMP of above 2 mbar over 10 min must not take place in beer filtrations of unfiltered Carlsberg pilsner 14.5 on a 0.1 m2 X-Flow filter with a length of 0.5 m within the first 10 min, if the permeate flux is 100 $l/h/m^2$. This can be accomplished by pumping the permeate out with a constant volume rate.

The backwash time/ backwash volume/backwash interval/cross-flow velocity in the fibres can, if necessary, be increased/decreased during a filtration run when the filter becomes increasingly fouled. Moreover, frequent or continuous backwashing with permeate or another liquid from a reservoir and with the permeate outlet(s) closed during filtration can also be applied once in a while for shorter times (e.g. minutes) in order to clean the membrane for possible particulate matter that has not been removed by the frequent backwashing.

The size of the minimum volume is for pre-cooled centrifuged unstabilised unfiltered Carlsberg pilsner 14.5 positively correlated to the haze number (it is possible that the viscosity or the density is of importance to the total performance). It constitutes typically from 2 to 9 ml per 0.1 m^2 filtration area (0.5 m long fibres, linear velocity 0.5 m/s, backwash interval 1.5 s) on a reverse asymmetric filter with an effective porosity of 80 % in the support layer and 20 % of the skin layer. Each fiber; i.d. 1.5 mm, O.D. 2.35 mm. This corresponds to 5 % to 25 % of the pore volume. The haze number of the beer constitutes in this case 0.5 to 9 EBC-T90 (European Brewery Convention, measurement angle 90°) for the non-upconcentrated beer, while the filtration rate constitutes a rate in the range of 100 to 300 $l/h/m^2$ or perhaps even higher.

It is an advantage to cool the beer at a pressure below the succeeding filtration system pressure as beer absorbs CO_2 if it is in contact with a CO_2-atmosphere that has a partial pressure higher than the equilibrium pressure of the beer. The pre-cooling at a lower CO_2-pressure minimises the risk for cavitation when backwashing. The cavitation in this case is identical to release of CO_2-bubbles from the beer. This has been observed in a filtration on beer in a 0.1 m^2 filter module (X-flow module with 0.5 m long fibres).

For the backwash to be effective it must not simply cause that gas-pockets at some place between the membrane inner side and the actuator are compressed. Thus, precaution against two possibilities for this should be taken. First, gas-pockets must be avoided before start-up. Second, creation of CO_2 bubbles/foam must be avoided. This is achieved by using a pressurised system, which reduces the risk of cavitation. A system pressure above 2.2 bar was needed in the filtrations performed by the inventors. The preferred system pressure will most probably depend on the equillibrium CO_2-pressure of the unfiltered beer.

The principles of the invention of providing flow facilitating means for retentate during back-washing and/or providing pressure controlling means for controlling the transmembrane pressure may be applied in many different ways by choosing different installation embodiments and adapting the operational conditions thereto such that different filtration requirements may be complied with.

In the following different ways of implementing the invention are described.

The figures 16 to 19 show different arrangements with filter modules with hollow fibre membranes.

In Figs. 16 and 17 the filtration is from the inside of the fibre to the outside. The feed goes into one end of the fibres and leaves as retentate at the other end. Some of it passes the membrane to the permeate side, where it can leave through the permeate outlet.

In Fig. 16 the backwash is performed by pressing permeate back through the backwash or permeate inlet. Buffers placed at the feed inlet and retentate outlet absorb the backwashed volume.

In Fig. 17 the backwash is performed by applying a pressure lower than the system pressure at the feed inlet and the retentate outlet. This will produce a "suction" effect that will attract liquid from the surroundings to the buffers. A buffer connected to the permeate inlet will supply liquid to means producing the "suction" effect.

Fig. 18 and Fig. 19 both show a filtration from the outside of the fibres to the inside. Permeate can be taken out at one or both ends of the fibres.

In Fig. 18 the backwash is performed by pressing permeate back through the membrane from the inside of the fibre to the outside thereof. It is important to apply the backpressure at both ends of the fibre to obtain the most uniform transmembrane pressure possible. The pressure drop along the fibres at the outside thereof is neglible compared to the pressure

drop at the inside thereof. Therefore it is sufficient with one pressure controlling buffer at the feed side. It is better to place the buffer at the feed inlet than at the retentate outlet, because it can also absorb the feed flow during backwash.

In Fig. 19 the backwash is performed by connecting the feed inlet of the fibres to a pressure lower than the system pressure for produce a "suction" effect as in Fig. 17. At the permeate side pressure controlling buffers are placed at both ends of the fibres to supply permeate to the "suction" device.

Fig. 20 shows a filtration installation utilizing the principle shown in Fig. 17. Two buffers 17 and 19 are connected at the feed and retentate ends of the filter module 1, respectively, through two valves 34. The valves 34 are closed during filtration. During filtration, two pumps 35 pump retentate from the buffers 17 and 19 into feed tank 36 so as to lower the pressure in the buffers to below the pressure in the rest of the installation. During backwash the valves 34 are opened. A buffer 33 at the permeate side supplies the permeate to flow back through the membrane into the buffers 17 and 19 because of the higher pressure in the buffer 33 (system pressure) than in the buffers 17 and 19..

Figure 21 shows a combination of the principles of Figs.16 and 17. Two cylinder/ piston devices 37 and 38 have one side of the pistons 37a and 38a in communication with the permeate side of the filter, and the other side of the pistons communicating with the retentate side of the filter.The pistons 37a and 38a are actuated by cam mechanisms 39 and 40, respectively, on the rotating cams of which the ends of piston rods 37b and 38b rest for moving the pistons 37a and 38a according to the contour of the cams and the rotational speed thereof. Any other suitable actuating means may be employed for actuating the pistons 37a and 38a.

During filtration the pistons 37a and 38a move in a direction that will fill one side of the pistons with permeate sucked from the housing 1 and empty the other side of retentate. During backwash the pistons are moved in reverse such that permeate is pressed into the housing 1 through inlet/outlets 41 and 42 while retentate is sucked into the respective piston chamber. This will press permeate through the membrane 2. This results in a combined pressing / sucking. By using different displacement patterns of the two pistons 37a and 38a, the distribution of the backwashed volume between the two permeate inlet/outlets 41 and 42 can be controlled.

Fig. 22 shows a way of implementing the principle of Fig. 16. A constant flow pump 43 is constantly pumping at a flow rate equal to the backwash flow rate. A loop with low flow re-

sistance (short length and large diameter conduit) interconnects the suction side and pressure side of the pump 43 over an open/close valve 44. An open/close valve 45 is arranged between the loop and pump 43 and the permeate inlet 3. During filtration, the valve 45 is closed and the valve 44 is open such that the pump 43 pumps the backwash flow rate around in the loop with small expenditure of energy. During backflush the valve 44 closes and the valve 45 opens such that the backwash flow is pumped into inlet 3 to create the backwashing transmembrane pressure.

Fig. 23 shows a way of performing the principle outlined in figure 17. A constant flow circulation pump 46 is arranged in a ciculation loop with low flow resistance and having a shunt throttle valve 47, the pump 46 furthermore being in communication with the retentate outlet 4. The loop with a suitable setting of the throttle valve 47 allows the pump 46 to pump a flow considerably higher than the system flow during filtration. During backwash, the valve 47 and a valve 48 upstream from the feed inlet 3 closes, forcing the pump 46 to suck permeate through the membrane. A buffer 49 for supplying permeate for the pump 46 during backwash is placed at the permeate side of the filter 1. To achieve a desired distribution of the backwashed volume, a by-pass 50 may be arranged in parallel with the filter 1. A throttle valve in the by-pass opens to a setting corresponding to the desired distribution during backwash.

Fig. 24 shows a filter housing 51 with built-in buffer 52. The housing 51 is larger than the bundle of fibres 2 allowing for a head-space 52 in one end. The filtration is from the outside of the fibres to the inside. Permeate is taken out one end 53 of the fibres. During backwash the backwash volume is divided between the two ends 53 and 54 of the fibres by means of valves 55 and 56. The head-space buffer 52 will absorb the backwashed volume.

Fig. 25 is an illustration of the possibility to combine the permeate inlet and the permeate outlet in one and the same aperture.

Fig. 26 shows a sanitary way of performing the backwash. A circumferential flexible wall 57 divides the filter housing 1 in a space for permeate and a space 58 for backwashing medium. During filtration a pump 59 pumps the backflush medium into a hydrophore 60 connected to the filter housing 1 through a valve 61. As a result the pressure in the hydrophore 60 increases. During backflush the valve 61 opens to allow the pressure to press the backflush medium back into the space 58.

In some cases it may be advantageous not to use pure permeate for backwashing. This might be the case in diafiltration or when filtering a concentrated liquid that is to be diluted

anyway. In these cases the addition of water can be combined with the backwashing. Fig. 27 shows a filtration installation that uses a mixture of permeate and water for backwashing. A constant flow pump 62 pumps permeate into a hydrophore 63 connected to the filter housing by an open/close valve 64 which when closed entails an increased pressure in the hydrophore as explained above. Another constant flow pump 65 pumps water into the hydrophore 63. When backwashing, the valve 64 opens to release the hydrophore pressure into the filter housing. The pump speeds of the two pumps 62 and 65 are adjusted so they together produce a volume corresponding to the backwash volume. The ratio between the flows of the two pumps can be altered during a filtration run.

Generally speaking, the pressure drop over the length of the fibres is much larger at the inside the fibres than at the outside. This causes a varying transmembrane pressure over the filter length, which again leads to an uneven distribution of the backwash volume. By introducing a flow resistance in the housing around the fibres, a pressure drop can also be obtained at the outside of the fibres. This is illustrated in Fig. 28, where the resistance is made up of several elements or inserts 66 obstructing the flow along the outside of the fibres 2. This results in discrete pressure drops along the filter length as shown in the qualitative pressure diagram.

A regulation of the permeate pressure drop during backwashing may also be realised filling the housing by eg. small steel balls. Another way to create a pressure drop along the fibres is to circulate permeate inside the filter housing by means of a pump 67. The two methods can be combined, as shown in figure 28. The pressure curves indicate the pressure drop at both the retentate side and the permeate side. As the transmembrane pressure is now more uniform, the backflushed volume will also have more even distribution.

The performance of the invention has been proven to be of commercial interest as shown by the non-limitative examples below.

Centrifuged, unstabilised/stabilised, unfiltered Carlsberg pilsner 14.5 has been used in all the cases except for comparative example V.

In all the examples except for comparative examples I, II, and V the unfiltered beer was stored overnight at 1 bar CO_2-pressure, and the system pressure at the inlet to the filter was 2.7 bar.

Comparative example No. I.

Wenten (Ph.D.thesis 1994. Technical University of Denmark. Application of cross-flow microfiltration for processing industrial suspensions) has published an up-concentration (batch mode) of 500 l to 5 l of a Carlsberg Pilsner type using a hollow fiber reverse asymmetric membrane 0.6 µm. The membrane supplier is X-Flow, who is mentioned as one of the suppliers of membranes. Thus, the membrane was an X-Flow filter MF08 M2 (0.6 µm) reverse asymmetric (made of polyethersulfone-polyvinylpyrrolidone) with a filtration area of 0.93 m^2. The principle of the experimental rig is shown in Figs 1 and 2 except that a heat exchanger was arranged between the pump and the inlet of the filter. The actual plant was a batch set-up, i.e. with no hydrophores and no low resistance conduits to a head space in a nearby tank. The cross-flow velocity, CV, was 0.5 m/s and the backwash time 0.1s. The temperature was not indicated but perhaps around 0 °C. An apparently nominel permeate flux of 150 $l/h/m^2$ was kept constant while TMP increased. The final TMP was 0.23 bar. The filtration time was 3.3 hours. There was no measurements on the haze content of the beer before and after the filtration. The applied backwash pressure was not indicated but was possibly 2 bar over the system pressure which was 1 bar.

Comparative example no. II.

Wenten (Ph.D.thesis 1994. Technical University of Denmark. Application of cross-flow microfiltration for processing industrial suspensions) has also published a filtration in industrial scale of almost 8 m^3 of the beer type above using a hollow fiber reverse asymmetric membrane 0.6 µm. The starting volume was not described. The filtration was performed in batch mode with an X-Flow filter MF08 M2 (0.6 µm) reverse asymmetric (made of polyethersulfone-polyvinylpyrrolidone) with an area of 9.3 m^2, upscaled from the experiment above. Then, the cross-flow velocity in the fibers, CV, has most certainly been 0.5 m/s and the backflush time possibly 0.1 s. The temperature was not indicated but perhaps around 0 °C. A rig of the type in Figs .1 and 2, i.e. with no pressure absorbers was applied except for that a heat exchanger was placed between the pump and the inlet of the filter. The apparently nominal permeate flux was 110 $l/h/m^2$. The final TMP was 0.7 bar and the filtration time 7 hours. There was no measurements on the haze content of the beer before and after the filtration. The applied backflush pressure was possibly 2 bar over the system pressure which was 1 bar.

Comparative example no. III.

In this experiment a cross-flow filtration in batch mode of stabilised beer was performed with an X-Flow filter MF08 M2 (0.6 μm) reverse asymmetric (made of polyethersulfone-polyvinylpyrrolidone) with an area of 0.93 m^2. A rig according to the principle in Fig.1. i.e. with no pressure absorbers, was applied except for that a heat exchanger was placed between the pump and the inlet of the filter and that a backwash system according to the invention of the type shown in Figs 3 and 4 was used. The actual rig is shown in Fig.41. except for that the membrane was a nominal 1 m^2 membrane. A backwash interval of 1.5 s and a cross-flow rate, CV, of 0.5 m/s were applied. The backwash volume was 160 ml in 150 ms. The temperature was –0.6 °C. The turbidity value of the unfiltered beer was 6.10 EBC-T90. The retentate pump was a centrifugal pump (Alfa-Laval, GM1), the positive pump for pumping total permeate out was a hose pump SP25, Bredel delden, and the pump for pumping backwash volume to the backwash hydrophore was a hose pump, SP10 (with a large hose), Bredel, Holland.

The theoretical pressure drop pattern in Fig.2. could not be documented. A trial was done but stopped almost immediately. The filtration system would have been damaged by the hard backwashes if the experiment had continued.

Comparative example no. IV.

An experiment on stabilised beer has been performed with an X-Flow filter MF08 M2 (0.6 μm) reverse asymmetric (made of polyethersulfone-polyvinylpyrrolidone) with an area of 0.93 m^2. The experimental set-up was the same as the one in comparative example III. A backflush interval of 1.5 s was applied. The backflush volume and time were 160 ml and 150 ms, respectively, as above and the temperature –2.3 °C, whereas the pump speed was much lower than in comparative example III. The feed flow varied between 0 and 600 l/h, which resulted in an average cross-flow rate of 0.12 m/s. Only 600 l out of the initial 900 l could be filtered before the filter fouled completely (fig. 29). The final TMP was 1.15 bar at 7.1 h. The permeate flux was 84 l/h/m^2. The permeate measured 0.63 to 0.75 EBC-T90. The value of the unfiltered beer was 6.10 EBC-T90. The pumps were the same as in comparative example III.

The theoretical pressure drop pattern in Fig. 2 could not be documented.

Following the experiment the filter could be cleaned with a procedure from Henkel-Ecolab using UF-filtered distilled water.

Comparative example no.V.

B. Czech, Schenk-Filterbau GmbH published on 34 Annual Convention 4/95 and in Filtrieren und Separieren (1995) pp. 21 the following results. The same type of beer as above was filtered in continuous mode with the set-up in fig. 30, i.e. without buffers with a CV of 0.5 m/s, a permeate rate of 100 l/h/m^2, and the same type of membrane but of 9.3 m^2. The longest filtration of 12 h was performed with recirculation of the permeate to the feed tank. The concentration factor was 1. The TMP was 1 bar. In the other trials where the concentration factor increased to 2 the performance was 7 hours or shorter. The backshock volume has most certainly been 150 ml in all the cases. The method described in EP 0 645 174 was followed.

Example No. I according to the new invention.

A trial with 870 l unfiltered unstabilised beer was filtered with the type of rig shown in Fig. 3 with a backflush pattern close to that in the same figure, except for that a heat exchanger was placed between the pump and hydrophore and the inlet of the filter. A drawing of the rig with all the used equipment is shown in Fig. 31. The installation was equipped with transducers (Haenni, model 510) to sample the pressures at the specfied points every 0.5 ms. The buffers were all flowmeters with apropiate clamps so they fuctioned according to their purpose as hydrophores. The buffer for the backwash volume was a Gemü (total volume 1.4 l ; inlet opening Ø 48 mm) Gebr. Müller, Germany, and the two buffers at the inlet and outlet to the filter a Gemü (total volume 1.8 l filled filled 2/3 with CO_2; inlet opening Ø 35 mm;), Gebr. Müller, Germany.

The retentate pump was a centrifugal pump (Alfa-Laval, GM1), the pump for pumping total permeate out was an excenter screw pump, Seepex, BC68 2, Seeberger GmbH, Germany, and the pump for pumping backflush volume to the backflush hydrophore was a hose pump SP25, Bredel delden, Holland. The cross-flow filtration (batch mode) was performed with an X-Flow filter MF08 M2 (0.6 μm) reverse asymmetric made of polyethersulfone-polyvinylpyrrolidone, 230 fibers in a bundle, each fiber i.d. 1.5 mm o.d. 2.35 mm, nominal length 1 m, filtration area 0.93 m^2. Its housing had a permeate outlet and an opening for inlet of backflush volume with a cross-section area of 9.6 cm^2. A backwash interval of 1.5 s and a CV of 0.5 m/s were applied. The backwash volume was 90 ml. The temperature varied between –0.5 and –1.2 °C.

All the beer was filtered with a permeate flux up to 370 l/h/m^2 (fig. 32). The backwash time was between 36 and 40 ms. The TMP was 0.280 bar when 70-80 l was left. Then, by mis-

take a large amount of CO_2 was blown into the feed. Anyway, the rest was also filtered, though the backwash system did not work. This must have caused the real permeate flux to drop as part of the volume was gas. The TMP ended at 0.60 bar. The permeate measured 0.71 EBC-T90. The value of the unfiltered beer was 2.99 EBC-T90. Clearly, it is possible to filter larger amounts of unfiltered beer than the 870 l. Up to 2000 l should be possible. The pressure curves (the pressure sensor numbers refer to Fig. 31) at 120 min is shown in Fig.33. The pressure at retentate in, P1 and P8, and retentate out, P5 and P6, are very nicely damped. This results in a very effective backwashing as seen in TMPin and TMPout. They are negative 100 % of the time.

Following the trial the filter could be cleaned with a procedure from Henkel-Ecolab using UF-filtered distilled water.

Example No. II according to the new invention.

An experiment was performed in continuous mode on a 0.1 m^2 module, with buffers, on up-concentrated beer. The rig for creation of the upconcentrated beer is the one shown in fig. 34 except for that the filter is not a 0.1 m^2 filter but the 1 m^2 filter above. The housing of the 1 m^2 filter was also the same. The beer was unstabilised. The installation is equipped with pressure transducers (Haenni, model ED 510) to sample the pressures at the specfied points every 0.5 ms. The buffer for baskflushing backflush volume was a Gemü (total volume 1.8 l), and the two buffers at the inlet and outlet to the filter a Gemü (total volume 1.4 l, filled with 1100 ml CO_2; inlet opening Ø 48 mm) Gebr. Müller, Germany, and a Gemü (total volume 1.8 , filled with 600 ml CO_2; inlet opening Ø 35 mm;), Gebr. Müller, Germany, respectively.

The pump in the loop is a centrifugal pump (Alfa-Laval, GM1), the pump for pumping total permeate out was an excenter screw pump, Seepex, BC68 2, Seeberger GmbH, Germany, and the pump for pumping backflush volume to the backflush hydrophore was a hose pump SP25, Bredel delden, Holland.

The starting volume was 300 l. 160 l of this was upconcentrated on a 0.93 m2 MF08 M2 RA filter from X-Flow. The volume was filtered in 23 min with an average flux of 423 l/h/m2. See fig. 35. Due to the very high flux rate the filter fouled relatively fast. The final TMP was 1.42 bar. The backflush interval 2 sec, the backflush volume 90 ml, and the backflush time 19.5 ms. The retentate flow 828 l/h.

The remaining volume, except for 10 l lost by exchange of filter, was filtered on the 0.1 m^2 module. See Fig.35. The rig is still the one in Fig. 34. The filter has just been replaced by the 0.1 m^2 module MF08 M2 RA filter from X-Flow and the pump for pumping total permeate out was was an excenter screw pump, Seepex, MD 0015, Interpump, Denmark, the pump for pumping backflush volume to the backflush hydrophore a hose pump SP10 (8056) Bredel Hose Pumps, Holland, and the pump for pumping bleed out a Seepex, MD 012, Interpump, Denmark.

The retentate flow was 180 l/h. The bleed flow changed a little due to problems with the tuning of the bleed pump, an excenter screw pump. This caused the concentration factor to increase from 22 to 29. See fig. 36. The backwash interval was 2 sec, the backwash volume 9 ml. The backwash time was 20 ms in the beginning, but 28 ms in the end. The flux was 133 l/h/m^2. The filtration continued to the dead volume of the system. The filtration took 9.25 h. The final TMP was 0.245 bar. The dead volume of the system was about 6.5 l.

The permeate quality is shown in table 3 below. All the estimated EBC-T90 values from after the first sample are satisfactory. The first samle measurement is too large. The measurements were performed on a haze meter from Dr. Weigang, Germany. (A non-authorized way to measure EBC-T90). The unit is FNU, which according to its brochure is 4 times the EBC-T90 value). This may explain the high estimated EBC-T90 value.

A pressure curve at 650 min (during the continuous filtration in 0.1 m^2 scale) is shown in Fig. 37. The pressure at the retentate in, P1, and retentate out, P5, are damped 100 %. No increase in pressure could be observed. The pressure peak of P3 shows that the permeate pressure increases to a high value during backwash. This results in TMPin and TMPout being negative 100 % of the time.

Table 3. Turbidity measurements on filtered beer from the filtration in continuous mode preceeded by a fast upconcentration.

Sample	FNU=4*EBC-T90	estimated EBC-T90
Unfiltered beer t= 0 min	10.28	2.57
Permeate sample 1	3.60	0.90
Permeate sample 2	1.27	0.32
Exchange of filter		
Permeate t=240 min	1.32	0.33
Permeate t=480 min	1.05	0.26
Permeate t=695 min	0.81	0.20
Bleed t=695 min	171.1	42.8

Example no.III according to the new invention.

A filter from Millipore, MILLIPORE EFD 125 LAB SCALE , was used. It has the following characteristics: 6 hollow fibers each 46 cm long twisted in parallel into a module with an effective fibre length of 23 cm. The pore size was 0.65 □m. The surface area was 0.0125 m^2. The fibers had an I.D. of 1.3 mm and O.D. of 2.0 mm. The fibres sustain pressures up to 1.4 bar. The housing sustains pressures up to 4.0 bar.

An experiment was performed on unstabilised beer in batch mode with a backwash pressure above the collapse pressure of the fibers as this was necessary to perform a fast backwashing. The rig is shown in fig.38. The pipes are of Ø 4 mm. A hydrophore (a 10 cm long piece of transparent stiff tube Ø 25 mm with a blind clamp in the end) is installed at the feed inlet. The installation is equipped with pressure transducers (Haenni, model ED510) to sample the pressures at the specified points every 0.5 ms. The feed pump is a centrifugal pump (Alfa-Laval, GM1), the pump for pumping total permeate out was a hose pump, SP10 (579), Wankesha Bredel, Holland, and the pump for pumping backflush volume to the backflush hydrophore was a hose pump SP10 (8056), Bredel Hose Pumps, Holland. The

cross-flow velocity in the fibers was 0.5 m/s. A backflush volume of 2.1 ml was used. The backflush interval was 2 s and the BF-time 22 ms. The temperature was –1.4 °C.

The permeate rate increased from 230 to 380 l/hm^2 as shown in the experimental results in Fig.39. The TMP did not increase much until the experiment was stopped after 4 h. The applied BF-pressure in the pressure chamber was 5 bar. The TMP increased only from 0.15 bar to 0.22 bar.

The turbidity measurement data are shown in table 4. This shows an acceptable turbidity of the filtered beer. Pressure curves at 230 min is shown in Fig. 40. It is seen that the BF-pressure is damped on the retentate side in the end of the feed inlet but not in the end of the retentate outlet, as there was no hydrophore here. Moreover, the permeate pressure is not oscillating but is has difficulties with decreasing to the system pressure, like the real BF-time is longer than the programmed one.

Table 4 Sample	EBC-T90
Unfiltered beer t=0	6.90
Permeate 1-4 h	0.79

Example no. IV according to the new invention.

An experiment has been performed on stablised beer on the rig described in the comparative example I with an X-Flow filter MF08 M2 (0.6 μm) reverse asymmetric (made of polyethersulfone-polyvinylpyrrolidone) with an area of 0.1 m^2. (50 fibers in a bundle each fiber i.d. 1.5 mm o.d. 2.35 mm, effective length 45 cm). The set-up was like the one in Fig. 2, i.e. with no pressure absorbers. A drawing of the rig is shown in Fig.41. The pipes had an I.D. of 20 mm. The length of the pipe pieces from the bottom of the feed tank to the filter inlet measured approx. 3.5 m and from the filter outlet to the feed tank approx. 5 m. The retentate pump was a centrifugal pump (Alfa-Laval, GM1), the pump for pumping total permeate out was a hose pump, SP10 (579), Wankesha Bredel, Holland, and the pump for pumping backflush volume to the backflush hydrophore was a hose pump SP10 (8056), Bredel Hose Pumps, Holland. The centrifugal pump worked with a very low frequency. The backwash system was the same as in comparative example III and IV. A backwash interval of 1.5 s was applied. The backwash time 40 ms. The backwash volume was 13 ml from t=0 to 7 h,

and 7 ml the remaining time. The temperature was –2 °C. The pump speed was 180 l/h corresponding to an average cross-flow velocity of 0.58 m/s. All 300 l was filtered except for 3 l that was left as dead volume. The final TMP was 0.29 bar. The average permeate flow was 14.8 l/h (fig. 42). The permeate measured 0.63 to 0.88 EBC-T90. The value of the unfiltered beer was 1.28 EBC-T90.

The pressure curves could not be documented but the curves of an analog filtration (the numbers refer to Fig.41) are shown in Fig.43.

Following the experiment the filter could be cleaned with a procedure from Henkel-Ecolab using UF-filtered distilled water.

Example no.V according to the new invention.

An experiment has been performed on stabilised beer on the same rig and with the same operating conditions as described in Example IV according to the new invention, only the following differed. The backwash volume was 3 ml. The backwash time 61 ms. The temperature was –1.5 °C.

All 300 l except for 23 l was filtered (Fig. 44). In the middle of the run the backwash valve failed. The 23 l unfiltered beer left at the end of the filtration can probably be ascribed to this failure. The final TMP was 0.50 bar. The permeate flux was 135 l/h/m^2. The permeate measured 0.53 to 0.71 EBC-T90. The value of the unfiltered beer was 2.66 EBC-T90. Following the trial the filter could be cleaned with a procedure from Henkel-Ecolab using UF-filtered distilled water.

Discussion of the examples.

The examples of the state of the art, the two comparative examples III and IV, and the examples according to the invention are compared in the following. Before doing this a success criteria is given. This is minimum 3000 l/m^2 filter area at flux of min. 100 l/hm2, if we are considering filtration of unstabilised/stabilised, unfiltered, centrifuged Carlsberg Pilsner 14.5 on an X-Flow filter MF08 M2 RA. This has been achieved by filtering 300 l on a 0.1 m2 X-Flow filter MF08 M2 RA at a flux of around 100 l/h/m^2 in several succeding filtrations with cleaning and restorage of the water permeability in between. The value will in the following be referred to as the reference value.

Moreover, beer filtration batch data of TMP versus time should only be compared if the concentration factor is below 4. The filterability is apparently reduced tremendously when the

technology of the state of the art is used, most probably due to creation of β-glucan gels, if the concentration factor is over 3 (ref. U.Gans, Die wirtschaftliche Crossflow-Microfiltration von Bier, Fortschr.-Ber. VDI Reihe 3. Nr.385. Düsseldorf: VDI-Verlag 1995). For a concentration factor over 3, the created β-glucan gels dominate the curves of flux and TMP versus time.

Comparative example I is a filtration starting with only 500 l/m^2. 495 l was filtered with a final TMP of 0.23 bar. 495 l is only 17 % of the reference value.

In comparative example II the starting volume is unknown. Almost 8 m^3 was filtered in 7.1 h with a final TMP of 0.7 bar on a 10 m^2 module of the type X-Flow MF08 M2 RA 0.6 □m. This performance is equal to 27 % of 3000 l/m^2 at 100 $l/h/m^2$.

Comparative example III did not result in any permeate as the filtration could not work at all.

Comparative example IV is a poor filtration of 600 l out of 900 l possible. The cross-flow velocity in the fibres was so low that the feed rate did only allow for feed enough for generation of permeate for backwashing which then during backwashing was led out of the filter outlet as retentate. Thus, it was actually a dead-end filtration.

Comparative example V shows results from continuous filtrations. 1 to 7 h filtrations at fluxes at around 100 $l/h/m^2$ were obtained. The membranes had a filter area of 10 m^2. The performances equals less than 23 % of 3000 l/m2 at 100 $l/h/m^2$.

The first example according to the invention shows a filtration of 870 l in 2.8 h (170 min) at flow rate of 311 l/h on a 1 m^2 X-Flow module of the type above. The equipment do not allow for more than 900 l as starting volume. 870 l is 29 % of 3000 l and this has been obtained in only 3.3 hours. Moreover, more beer could have been filtered if more beer had been available. There could have been filtered about 1200 l/m^2 at 311 l/h. That means that 40 % of 3000 l could have been filtered at a nominel flux rate of 311 l/hm^2. Suppose the flux had been only 100 $l/h/m^2$ the filtration time would probably have been much longer than 8.7 h as more beer could be filtered and because the tendency to fouling depends strongly on the permeate flux rate.

The second example is on a 0.1 m^2 X-Flow filter of the type above. It was in continuous mode and the concentration factor was around 25. In only 9.25 h 124 l was filtered with a permeate flux of 133 l/hm^2 and the final TMP was 0.245 bar. This equals 41 % of the reference value. If there had been more beer to filter the documentated performance would

have been much better. That would also have been the case if the permeate flux had only been 100 l/h/m^2.

The third example with the Millipore filter shows that in 250 min about 15 l or 1200 l/ m^2 has been filtered. This is 40 % of the reference value and shows the promising result that also on a normal asymmetric membrane it is useful for economical feasible beer filtrations according to the invention.

The forth and fifth examples are on 0.1 m2 X-Flow filters in batch mode. In both cases 3000 l/m^2 was filtered. This is 100 % of the reference value. The experiments are the only ones on which it is possible to document a performance around the reference value with a limitation on the feed volume of 900 l. The other examples did not show performance closer then 40 % of the reference value due to the above limitation of feed volume.

To conclude, the results form the examples in 0.1 m2 scale according to the invention shows much better performance than the state of the art (ref. U.Gans, Die wirtschaftliche Crossflow-Microfiltration von Bier, Fortschr.-Ber. VDI Reihe 3. Nr.385. Düsseldorf: VDI-Verlag 1995), while the filtration result in 1 m2 scale according to the invention shows a performance that is at least twice as good than the state of the art, as the filtration has been performed in less than half the time. Moreover, an even better result could have been obtained if more beer had been avaible and if the permeate flux rate had been the normal of 100 l/hm^2.

The module thickness has no significant importance (the 10 m^2 modules, measured by the radius of the bundle, are only 3.16 times thicker than the 1 m^2 modules) as there is no significant pressure drop in radial direction of the fiber bundles. The Ergun equation (Bend Research, Brose et al., Final report to FLS Miljø A/S from Bend Research INC, 1991) can be used for calculation of the pressure drop. The pressure drop in radial direction of the fiber bundle can be calculated to around 0.5 kPa/m. Thus, even for the 10 m^2 X-Flow module, this pressure drop will be insignificant to the pressure drop in axial direction inside the fibers. From this it is concluded that filtration results of at least twice the performance of the state of art can be obtained in 10 m^2 X-Flow modules.

Second, the invention is not limited to X-Flow filters, other filters, also normal asymmetric filters and symmetric filters can be applied as well. The companies known to manufacture fibres and who will be able to make hollow fibers usefull for beer filtration according to the new invention are: X-Flow, Millipore, Sepromembranes, Zenon.

The invention may be applicable to spiral wound modules. On the feed side it should be possible to place hydrophores before and after the filter module. On the permeate side it should be possible to apply a short but large enough and frequent pressure, so permeate goes back through the whole membrane area. The success depends on the strength and dimension of the spiral module in question.

Finally, it should be pointed out that the principles of the invention are not only applicable to microfiltration but may also be applied to ultrafiltration and macrofiltration with backwashing.

CLAIMS

1. A method of cross-flow filtration of a fluid utilizing a permeable membrane between the retentate and the permeate of the fluid for retaining particles present in said fluid in said retentate, the method comprising the steps of:

– applying a first pressure differential between the retentate and the permeate for driving the fluid through the membrane in a filtering direction and causing the fluid to flow along the surface of the membrane facing the retentate during a filtering phase,

– periodically backwashing the membrane by applying a second pressure differential between the permeate and the retentate during a period of time for driving the fluid back through the membrane in a backwashing direction during a backwashing phase,

– facilitating the flow of retentate relative to the membrane during said backwashing phase such that a substantial transport of retentate along and/or away from substantially all portions of the surface of the membrane facing the retentate is achieved during said backwashing phase.

2. A method according to claim 1 and comprising the further step of:

– facilitating the flow of permeate relative to the membrane during said backwashing phase such that a substantial transport of permeate towards and/or along substantially all portions of the surface of the membrane facing the permeate is achieved during said backwashing phase.

3. A method according to claim 1 or 2, wherein the membrane is arranged in a filter housing having a feed inlet, a retentate outlet, a permeate inlet and a permeate outlet or a combined permeate outlet and inlet.

4. A method according to claim 3 and comprising the further steps of:

– providing permeate flow facilitating means for facilitating said flow of permeate and comprising a buffer container or hydrophore having a gas filled head space and a fluid filled space and arranged with the fluid filled space in fluid communication with said permeate inlet through a conduit with low flow resistance and in fluid communication with a constant flow pump, an open/close valve being ar-

ranged to open and close the fluid communication through said conduit between said fluid filled space and said permeate inlet,

– operating said constant flow pump continuously during both said filtering phase and said backwashing phase at a rate achieving a pumped volume during a filtering phase and the subsequent backwashing phase substantially equal to the desired backwashed volume of permeate in a backwashing phase,

– opening said open/close valve during said backwashing phase and closing said open/close valve during said filtering phase,

such that any increase in flow resistance through said membrane in the backwashing direction will entail an increase of the volume of said fluid filled space with a corresponding increase of the pressure in said gas filled head space.

5. A method according to claim 3 and comprising the further steps of:

– providing permeate flow facilitating means for facilitating said flow of permeate and

– comprising a constant flow pump in interruptable fluid communication with said permeate inlet for providing the permeate flow in said backwashing direction, and

– maintaining said constant flow pump in fluid communication with said permeate inlet during said backwashing phase at a rate achieving a pumped volume during said period of time substantially equal to the desired backwashed volume of permeate, and

– interrupting said fluid communication between said constant flow pump and said permeate inlet during said filtering phase.

6. A method according to claim 4 or 5, and comprising the further step of:

– providing a flow resistance means such as a valve and adapted for periodically reducing or stopping the flow of permeate through said permeate outlet, and

– activating said flow resistance means during said backwashing phase such that the flow of permeate through said permeate outlet is reduced or stopped.

7. A method according to any of the claims 3 - 6 and further comprising the step of:

   – controlling the permeate pressure along the flow path of the permeate during said backwashing phase such that said permeate pressure is reduced substantially along said path, preferably reduced substantially corresponding to the reduction of the retentate pressure along the flow path of the retentate.

8. A method according to claim 7, wherein one or more flow resistance bodies or spacers are arranged in said permeate flow path and/or a pump is arranged in fluid communication with said permeate inlet and outlet for pumping permeate from said permeate outlet to said permeate inlet during the backwashing phase.

9. A method according to any of the claims 1-8, wherein said second pressure differential is achieved by during said backwashing phase reducing the pressure of the retentate relative to the retentate pressure during said filtering phase and/or by during said backwashing phase increasing the pressure of the permeate relative to the permeate pressure during said filtering phase.

10. A method according to any of the claims 3-9 and comprising the further step of:

   – providing retentate flow facilitating means in fluid communication with said feed inlet and/or said retentate outlet for facilitating said flow of retentate from said feed inlet and/or said retentate outlet during said backwashing phase.

11. A method according to claim 10, wherein said retentate flow facilitating means comprise a first low flow resistance fluid conduit in fluid communication with said feed inlet and/or a second low flow resistance fluid conduit in fluid communication with said retentate outlet.

12. A method according to claim 10 or 11, wherein said retentate flow facilitating means comprise a first retentate reception means such as a buffer tank or a hydrophore in fluid communication with said feed inlet for receiving retentate from said feed inlet and/or a second retentate reception means such as a buffer tank or a hydrophore in fluid communication with said retentate outlet for receiving retentate from said retentate outlet during said backwashing phase

13. A method according to claim 12 and comprising the further steps of:

   – providing an open/close valve between said first retentate reception means and

said fluid inlet and/or between said second retentate reception means and said retentate outlet,

– closing said open/close valve or valves during said filtering phase,

– reducing the pressure in said first and/or second retentate reception means to a pressure substantially below the pressure of the retentate in said filtering phase,

– opening said open/close valve or valves during said backwashing phase.

14. A method according to any of the claims 1-13, wherein the membrane is an asymmetric membrane.

15. A method according to any of the claims 1-13, wherein the membrane is a reverse asymmetric membrane.

16. A method according to any of the claims 1-13, wherein the membrane is a symmetric membrane.

17. A method according to any of the claims 1-16, wherein the membrane has a mean pore size diameter between approx 0.2 micrometre and approx. 1.0 micrometre and has a permeability for water of more than approx. 5,000 l/h/m2/bar, more preferably more than 10,000l/h/m2/bar, further preferably more than approx. 15,000 l/h/m2/bar, further preferably more than approx. 20,000 l/h/m2/bar, further preferably more than approx. 25,000 l/h/m2/bar and most preferably more than approx. 30,000 l/h/m2/bar.

18. A method according to any of the claims 3-17, wherein said second pressure differential between the permeate and the retentate at said feed inlet and said retentate outlet is maintained positive during at least 60% of said period of time, preferably at least 70%, further preferably at least 80%, most preferably at least 85% of said period of time.

19. A method according to any of the preceding claims and for use in filtration of beer, wherein the time interval between consecutive backwashing phases is between approx. 0.5 sec and approx. 10 sec, said second pressure differential is between approx. 0.005 bar and approx. 6 bar, and the duration of each backwashing phase is between approx. 10 ms and approx. 5sec.

20. A cross-flow filtration installation for removing particles from a fluid and comprising:

- a permeable membrane having a retentate side and a permeate side and arranged in a housing having a feed inlet and a retentate outlet, the housing also being provided with a permeate outlet and a permeate inlet or a combined permeate outlet and inlet,

- first pressure generating means for generating a first pressure differential between the retentate side and the permeate side for driving the fluid through the membrane in a filtering direction and causing the fluid to flow along the surface of the membrane facing the retentate during a filtering phase,

- second pressure generating means for periodically generating a second pressure differential between the permeate side and the retentate side during a period of time for driving the fluid back through the membrane in a backwashing direction during a backwashing phase, and

- retentate flow facilitating means for facilitating the flow of retentate relative to the membrane during said backwashing phase such that a substantial transport of retentate along and/or away from substantially all portions of the surface of the membrane facing the retentate is achieved during said backwashing phase.

21. A filtration installation according to claim 20 and further comprising:

- permeate flow facilitating means for facilitating the flow of permeate relative to the membrane during said backwashing phase such that a substantial transport of permeate towards and/or along substantially all portions of the surface of the membrane facing the permeate is achieved during said backwashing phase.

22. A filtration installation according to claim 20 or 21, wherein said permeate flow facilitating means comprise:

- a buffer container or hydrophore having a gas filled head space and a fluid filled space,

- a conduit with low flow resistance arranged for establishing fluid communication between said fluid filled space and said permeate inlet,

- a constant flow pump arranged in fluid communication with said conduit, and

- an open/close valve arranged in said conduit such as to open and close the fluid

communication through said conduit between said fluid filled space and said permeate inlet and between said constant flow pump and said permeate inlet,

- said constant flow pump having a pumping rate at least sufficient for achieving a pumped volume during a filtering phase and the subsequent backwashing phase substantially equal to the desired backwashed volume of permeate during a backwashing phase.

23. A filtration installation according to claim 20 or 21, wherein said permeate flow facilitating means comprise:

- a constant flow pump in fluid communication with said permeate inlet and having a pumping rate at least sufficient for achieving a pumped volume during a backwashing phase substantially equal to the desired backwashed volume of permeate during said backwashing phase, and

- flow interrupting means such as a valve arranged for interrupting said fluid communication between said constant flow pump and said permeate inlet.

24. A filtration installation according to any of the claims 20-23 and further comprising a flow resistance means such as a valve arranged for periodically reducing or stopping the flow of permeate through said permeate outlet during said backwashing phase.

25. A filtration installation according to any of the claims 20-24 and further comprising permeate pressure controlling means for controlling the permeate pressure along the flow path of the permeate between said permeate inlet and said permeat outlet during said backwashing phase such that said permeate pressure is reduced substantially along said path.

26. A filtration installation according to claim 25, wherein said permeate pressure controlling means comprise one or more flow resistance bodies or spacers arranged in said permeate flow path and/or a pump arranged in fluid communication with said permeate inlet and outlet for pumping permeate from said permeate outlet to said permeate inlet during said backwashing phase.

27. A filtration installation according to any of the claims 20-26 and further comprising:

- retentate flow facilitating means in fluid communication with said feed inlet and/or said retentate outlet for facilitating said flow of retentate from said feed

inlet and/or said retentate outlet during said backwashing phase.

28. A filtration installation according to claim 27, wherein said retentate flow facilitating means comprise a first low flow resistance fluid conduit in fluid communication with said feed inlet and/or a second low flow resistance fluid conduit in fluid communication with said retentate outlet.

29. A filtration installation according to claim 27 or 28, wherein said retentate flow facilitating means comprise a first retentate reception means such as a buffer tank or a hydrophore in fluid communication with said feed inlet for receiving retentate from said feed inlet and/or a second retentate reception means such as a buffer tank or a hydrophore in fluid communication with said retentate outlet for receiving retentate from said retentate outlet during said backwashing phase

30. A filtration installation according to claim 29 and further comprising:

- an open/close valve between said first retentate reception means and said fluid inlet and/or between said second retentate reception means and said retentate outlet, and

- pressure reducing means such as a pump for reducing the pressure in said first and/or second retentate reception means to a pressure substantially below the pressure of the retentate during said filtering phase.

31. A filtration installation according to any of the claims 20-30, wherein the membrane is configured as one or more tubular bodies, each tubular body having an internal lumen adajcent an internal surface of the tubular body, and an exterior surface.

32. A filtration installation according to claim 31, wherein said interior surface constitutes said retentate side of the membrane and said exterior surface constitutes said permeate side of the membrane.

33. A filtration installation according to claim 31, wherein said interior surface constitutes said permeate side of the membrane and said exterior surface constitutes said retentate side of the membrane.

34. A filtration installation according to any of the claims 31-33, wherein said housing comprises a gas filled head space

35. A filtration installation according to claim 34, wherein said gas filled head space is

separated from the remaining volume of said housing by a displaceable barrier such as a sheet of resilient material or a partition wall arranged displaceable in said housing in a direction transverse to the plane of said partition wall.

36. A filtration installation according to claim 32, wherein said housing comprises a fluid filled space separated from the remaining volume of said housing by a displaceable barrier such as a sheet of resilient material or a partition wall arranged displaceable in said housing in a direction transverse to the plane of said partition wall, said fluid filled space communicating with the exterior of said housing by means of a fluid aparture preferably substituting said permeate inlet.

37. A filtration installation according to any of the claims 20-36, wherein the membrane is an asymmetric membrane.

38. A filtration installation according to any of the claims 20-36, wherein the membrane is a reverse asymmetric membrane.

39. A filtration installation according to any of the claims 20-36, wherein the membrane is a symmetric membrane.

40. A filtration installation according to any of the claims 20-39, wherein the membrane has a mean pore size diameter between approx 0.2 micrometre and approx. 1.0 micrometre and has a permeability for water of more than approx. 5,000 l/h/m2/bar, more preferably more than 10,000l/h/m2/bar, further preferably more than approx. 15,000 l/h/m2/bar, further preferably more than approx. 20,000 l/h/m2/bar, further preferably more than approx. 25,000 l/h/m2/bar and most preferably more than approx. 30,000 l/h/m2/bar.

41. A method of cross-flow filtration of a fluid utilizing a permeable membrane between the retentate and the permeate of the fluid for retaining particles present in said fluid in said retentate, the method comprising the steps of:

– applying a first pressure differential between the retentate and the permeate for driving the fluid through the membrane in a filtering direction and causing the fluid to flow along the surface of the membrane facing the retentate during a filtering phase,

– periodically backwashing the membrane by applying a second pressure differential between the permeate and the retentate during a period of time for driv-

ing the fluid back through the membrane in a backwashing direction during a backwashing phase,

– controlling the pressure on the retentate side and the permeate side of the membrane over time and/or along the filtering extent of the membrane both during the filtering phase and during the backwashing phase such that the desired flow characteristics are obtained along part of or the entire filtering extent of the membrane.

42. A method according to claim 41, wherein the membrane is arranged in a filter housing having a feed inlet, a retentate outlet, a permeate inlet and a permeate outlet or a combined permeate outlet and inlet, a pressure controlling means for controlling the fluid pressure during said backwashing phase such as a buffer container or a hydrophore and/or a constant pressure pump, preferably a low resistance constant pressure pump, being arranged at or near said permeate inlet for backwashing re-delivery of previosuly removed permeate and at or near said feed inlet and preferably also at or near said retentate outlet.

43. A method according to claim 42, wherein a low flow resistance fluid conduit is arranged between one or more of the pressure controlling means and the membrane.

44. A method according to any of the claims 40-43, wherein the membrane is an asymmetric membrane.

45. A method according to any of the claims 40-43, wherein the membrane is a reverse asymmetric membrane.

46. A method according to any of the claims 40-43, wherein the membrane is a symmetric membrane.

47. A method according to any of the claims 40-46, wherein the membrane has a mean pore size diameter between approx 0.2 micrometre and approx. 1.0 micrometre and has a permeability for water of more than approx. 5,000 l/h/m2/bar, more preferably more than 10,000l/h/m2/bar, further preferably more than approx. 15,000 l/h/m2/bar, further preferably more than approx. 20,000 l/h/m2/bar, further preferably more than approx. 25,000 l/h/m2/bar and most preferably more than approx. 30,000 l/h/m2/bar.

48. A method according to any of the claims 42-47, wherein said second pressure differential between the permeate and the retentate at said feed inlet and said retentate

outlet is maintained positive during at least 60% of said period of time, preferably at least 70%, further preferably at least 80%, most preferably at least 85% of said period of time.

49. A method according to any of the claims 40-48 and for use in filtration of beer, wherein the time interval between consecutive backwashing phases is between approx. 0.5 sec and approx. 10 sec, said second pressure differential is between approx. 0.005 bar and approx. 6 bar, and the duration of each backwashing phase is between approx. 10 ms and approx. 5sec.

50. A cross-flow filtration installation for removing particles from a fluid and comprising

– a permeable membrane having a retentate side and a permeate side and arranged in a housing having a feed inlet and a retentate outlet, the housing also being provided with a permeate outlet and a permeate inlet or a combined permeate outlet and inlet,

– a first conduit for supplying fluid to said feed inlet, a second conduit for receiving retentate from said retentate outlet, a third conduit for receiving permeate from the permeate outlet, and a fourth conduit for re-delivering permeate to said permeate inlet for backwashing,

– first pressure means for applying pressure in said first conduit and/or second pressure means for applying pressure in said second conduit and/or third pressure means for applying pressure in said third conduit and/or fourth pressure means for applying pressure in said fourth conduit,

– pressure controlling means for controlling the pressure applied by one or more of said pressure means for controlling the pressure on the retentate side and the permeate side of the membrane over time and/or along the extent of the membrane both during a filtering phase and during a backwashing phase such that the desired flow characteristics of the retentate and permeate are obtained along part of or the entire extent of the membrane.

51. A filtration installation according to claim 50, wherein one or more of said pressure means comprises a pressure buffer container or a hydrophore and/or a constant pressure pump, preferably a low resistance constant pressure pump.

52. A filtration installation according to claim 50 or 51, wherein one or more of said first,

second, third and fourth conduits comprises a conduit with low flow resistance.

53. A filtration installation according to any of the claims 50-52, wherein the membrane is an asymmetric membrane.

54. A filtration installation according to any of the claims 50-52, wherein the membrane is a reverse asymmetric membrane.

55. A filtration installation according to any of the claims 50-52, wherein the membrane is a symmetric membrane.

56. A filtration installation according to any of the claims 50-55, wherein the membrane has a mean pore size diameter between approx 0.2 micrometre and approx. 1.0 micrometre and has a permeability for water of more than approx. 5,000 l/h/m2/bar, more preferably more than approx.10,000l/h/m2/bar, further preferably more than approx. 15,000 l/h/m2/bar, further preferably more than approx. 20,000 l/h/m2/bar, further preferably more than approx. 25,000 l/h/m2/bar and further preferably more than approx. 30,000 l/h/m2/bar.

57. A method of cross-flow filtration of a fluid utilizing a permeable membrane between the retentate and the permeate of the fluid for retaining particles present in said fluid in said retentate, the method comprising the steps of:

- applying a first pressure differential between the retentate and the permeate for driving the fluid through the membrane in a filtering direction and causing the fluid to flow along the surface of the membrane facing the retentate during a filtering phase,

- periodically backwashing the membrane by applying a second pressure differential between the permeate and the retentate during a period of time for driving the fluid back through the membrane in a backwashing direction during a backwashing phase,

- controlling said second pressure differential in accordance with the flow resistance through said membrane in the backwashing direction such that an increase in said flow resistance from one backwashing phase to the subsequent backwashing phase automatically entails a corresponding increase in said second pressure differential.

58. A method according to claim 57, wherein the membrane is arranged in a filter housing having a feed inlet, a retentate outlet, a permeate inlet and a permeate outlet or a combined permeate outlet and inlet, the method comprising the further steps of:

- providing pressure controlling means for controlling the permeate pressure and comprising a buffer container or hydrophore having a gas filled head space and a fluid filled space and arranged with the fluid filled space in fluid communication with said permeate inlet and in fluid communication with a constant flow pump, an open/close valve being arranged to open and close the fluid communication between said fluid filled space and said permeate inlet,

- operating said constant flow pump continuously during both said filtering phase and said backwashing phase at a rate achieving a pumped volume during a filtering phase and the subsequent backwashing phase substantially equal to the desired backwashed volume of permeate in a backwashing phase,

- opening said open/close valve during said backwashing phase and closing said open/close valve during said filtering phase,

such that any increase in said flow resistance through said membrane in the backwashing direction will entail an increase of the volume of said fluid filled space with a corresponding increase of the pressure in said gas filled head space.

59. A method according to claim 57, wherein the membrane is arranged in a filter housing having a feed inlet, a retentate outlet, a permeate inlet and a permeate outlet or a combined permeate outlet and inlet, the method comprising the further steps of:

- providing pressure controlling means for controlling the permeate pressure and comprising a constant flow pump in interruptable fluid communication with said permeate inlet for providing the permeate flow in said backwashing direction, and

- maintaining said constant flow pump in fluid communication with said permeate inlet during said backwashing phase at a rate achieving a pumped volume during said period of time substantially equal to the desired backwashed volume of permeate, and

- interrupting said fluid communication between said constant flow pump and said permeate inlet during said filtering phase.

60. A method according to claim 58 or 59, the pressure controlling means further comprising a flow resistance means such as a valve and adapted for periodically reducing or stopping the flow of permeate through said permeate outlet, the method comprising the further steps of:

   – activating said flow resistance means during said period of time such that the flow of permeate through said permeate outlet is reduced or stopped.

61. A cross-flow filtration installation for removing particles from a fluid and comprising:

   – a permeable membrane having a retentate side and a permeate side and arranged in a housing having a feed inlet and a retentate outlet, the housing also being provided with a permeate outlet and a permeate inlet or a combined permeate outlet and inlet, and

   – pressure controlling means for controlling the permeate pressure and adapted for automatically increasing the pressure of the permeate at said permeate inlet when the flow rate into said permeate inlet decreases.

62. A filtration installation according to claim 61, wherein said pressure controlling means comprise a buffer container or hydrophore having a gas filled head space and a fluid filled space and arranged with the fluid filled space in fluid communication with said permeate inlet and in fluid communication with a constant flow pump, an open/close valve being arranged between said fluid filled space and said permeate inlet so as to open and close the fluid communication between said fluid filled space and said permeate inlet,

63. A filtration installation according to claim 61, wherein said pressure controlling means comprise a constant flow pump in fluid communication with said permeate inlet for providing backwashing permeate flow into said permeate inlet.

64. A filtration installation according to any of the claims 62-63, wherein the pressure controlling means further comprise a flow resistance means such as a valve adapted for periodically reducing or stopping the flow of permeate through said permeate outlet.

65. A cross-flow filter for removing particles from a liquid and comprising a housing having a feed inlet, a retentate outlet, a permeate outlet and a permeate inlet, one or more tubular members made of a filtration membrane and arranged in said housing, the

housing having a gas filled head space and a fluid filled space

66. A filter according to claim 65, wherein the fluid in said fluid filled space is in fluid communication with said feed inlet and said retentate outlet and the lumens of said tubular members are in fluid communication with said permeate inlet and said permeate outlet..

67. A filter according to claim 65, wherein said fluid filled space is in communication with said permeate inlet and said permeate outlet and the lumens of said tubular members are in fluid communication with said feed inlet and said retentate outlet.

68. A filter according to any of the claims 65-67, wherein said gas filled head space is separated from the remaining volume of said housing by a displaceable barrier such as a sheet of resilient material or a partition wall arranged displaceable in said housing in a direction transverse to the plane of said partition wall.

Fig. 1

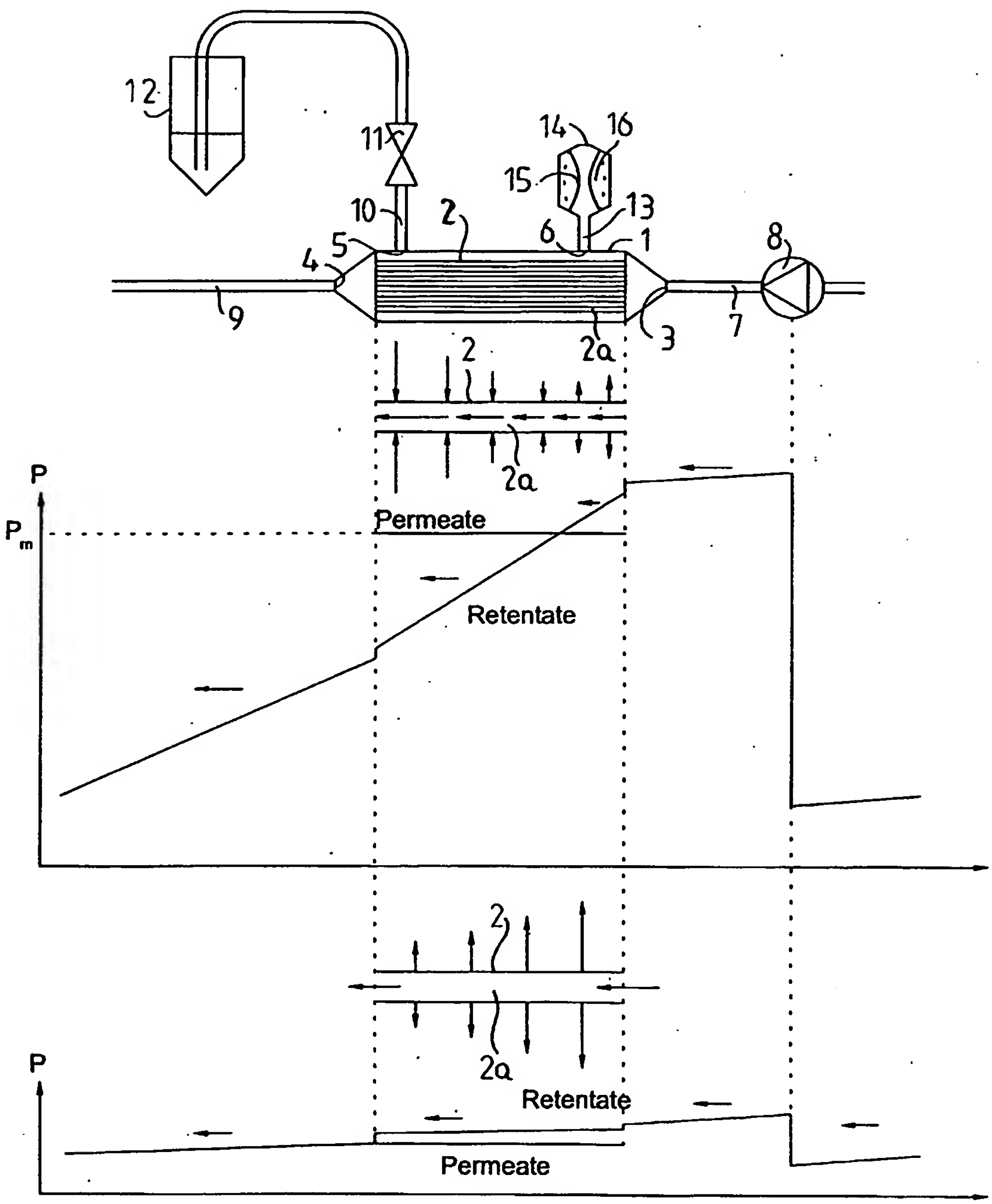

12
11
10
2
14
16
15
13
6
1
8
5
4
9
2a
3
7
P
P_m
Permeate
Retentate
Retentate
Permeate

Fig. 2

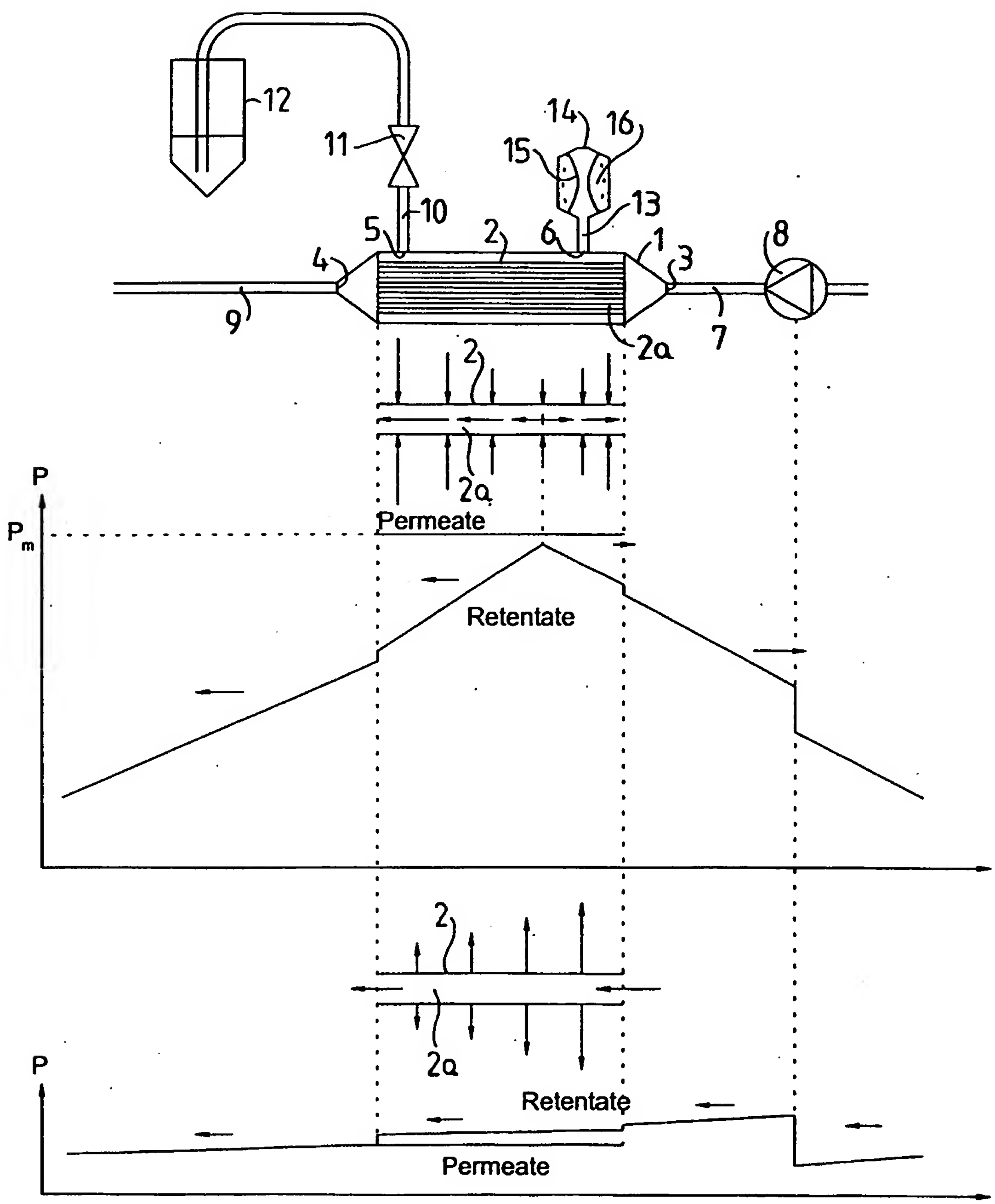
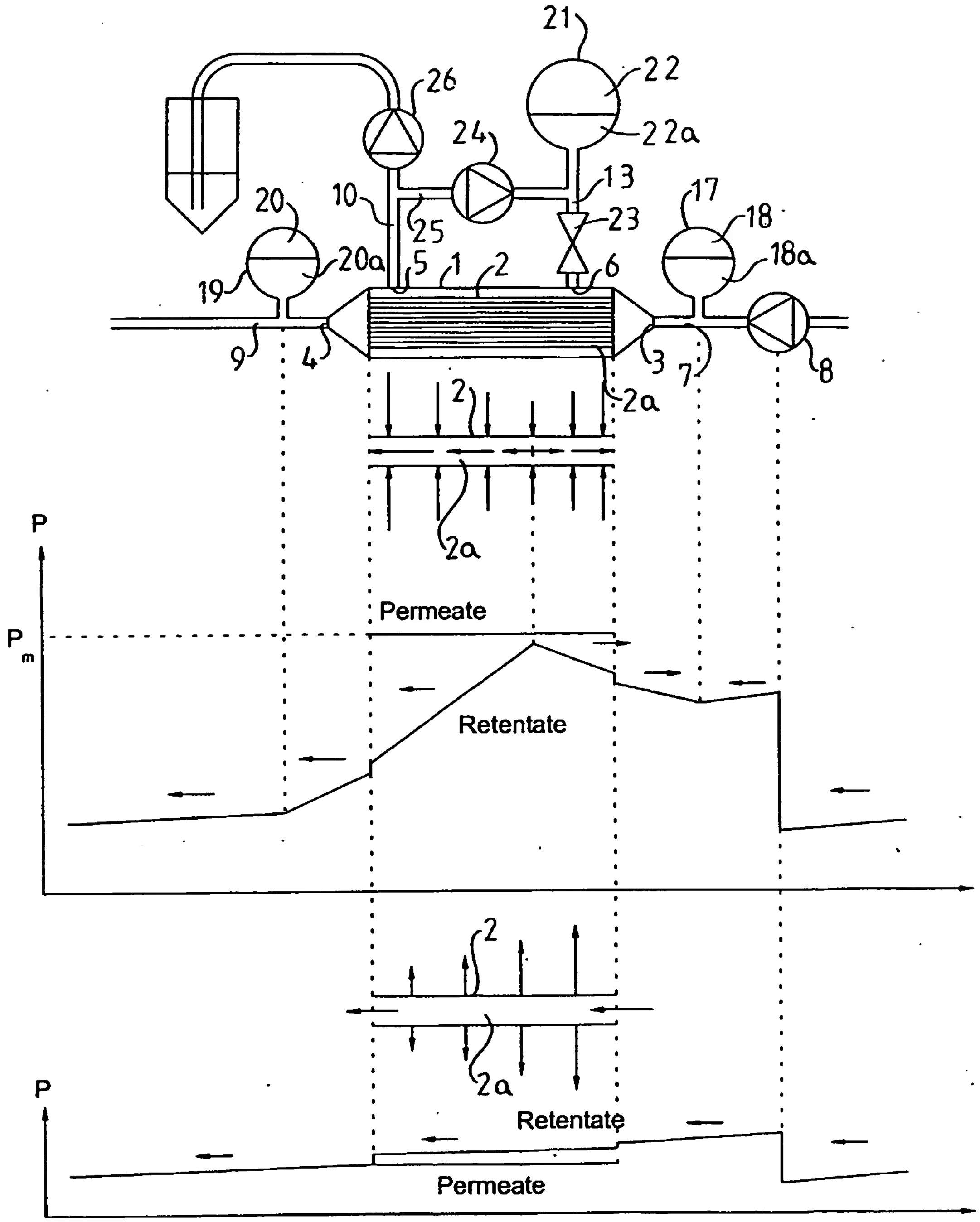

12
11
10
14
16
15
13
5
2
6
1
4
3
8
9
2a
7
2
2a
P
P_m
Permeate
Retentate
2
2a
P
Retentate
Permeate

Fig. 3



21
22
22a
26
24
13
23
10
25
20
20a
19
5
1
2
6
17
18
18a
9
4
3
7
8
2a
2
2a
P
Permeate
P_m
Retentate
2
2a
P
Retentate
Permeate

Fig. 4

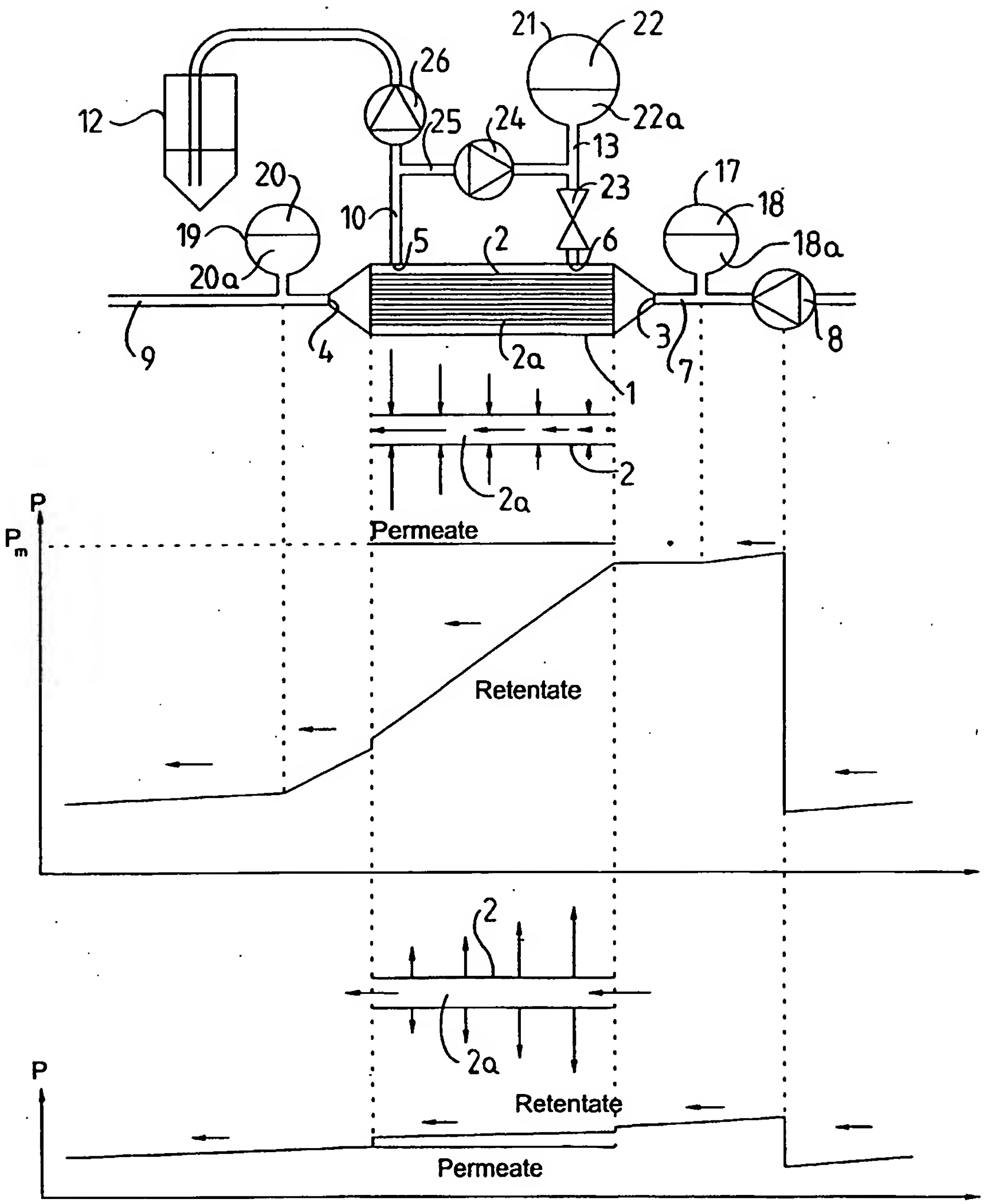

21
22
26
12
25
24
22a
13
20
23
17
10
18
19
5
2
6
18a
20a
9
4
2a
3
8
7
1
2
2a
P
P_m
Permeate
Retentate
2
2a
P
Retentate
Permeate

Fig. 5

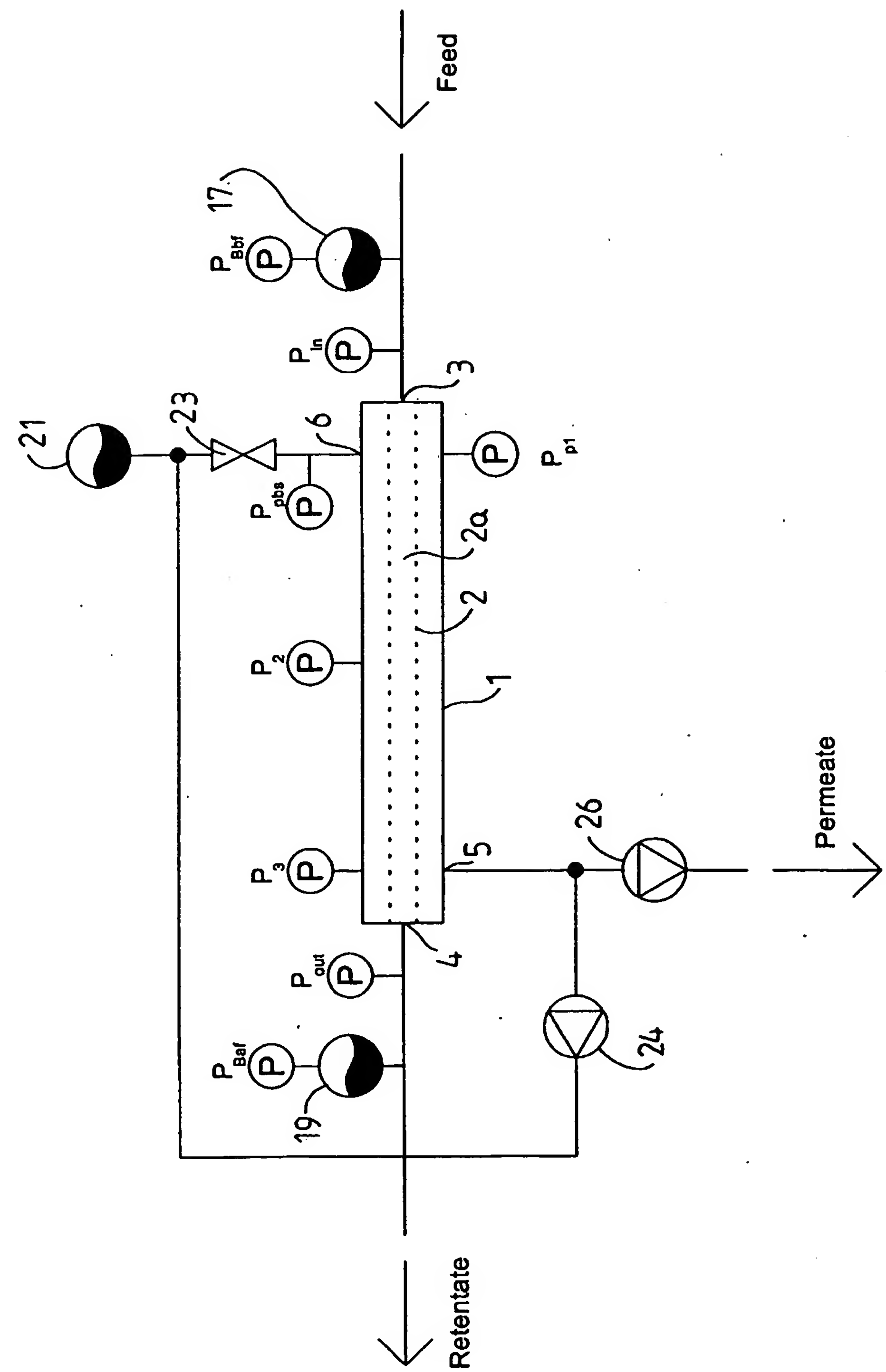
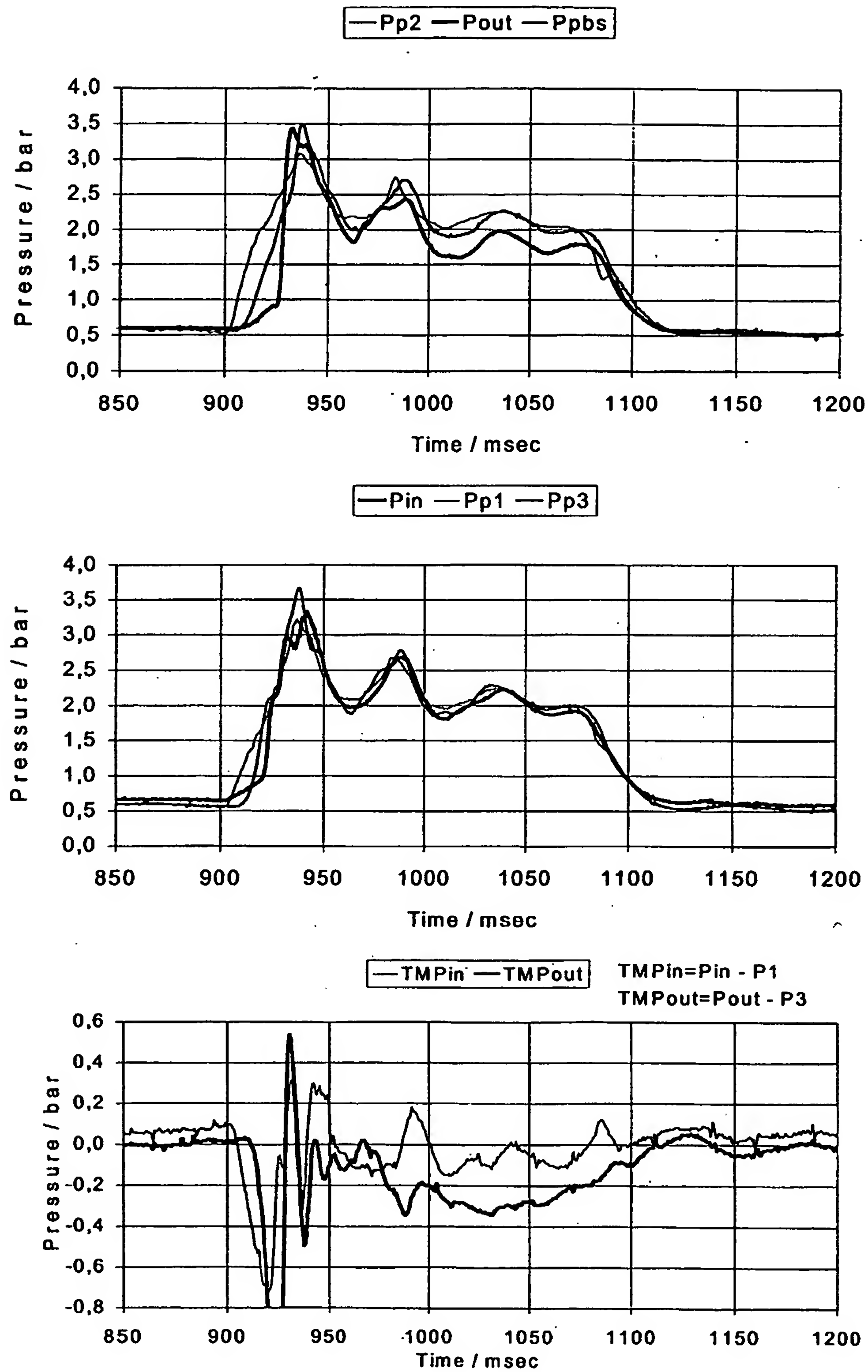
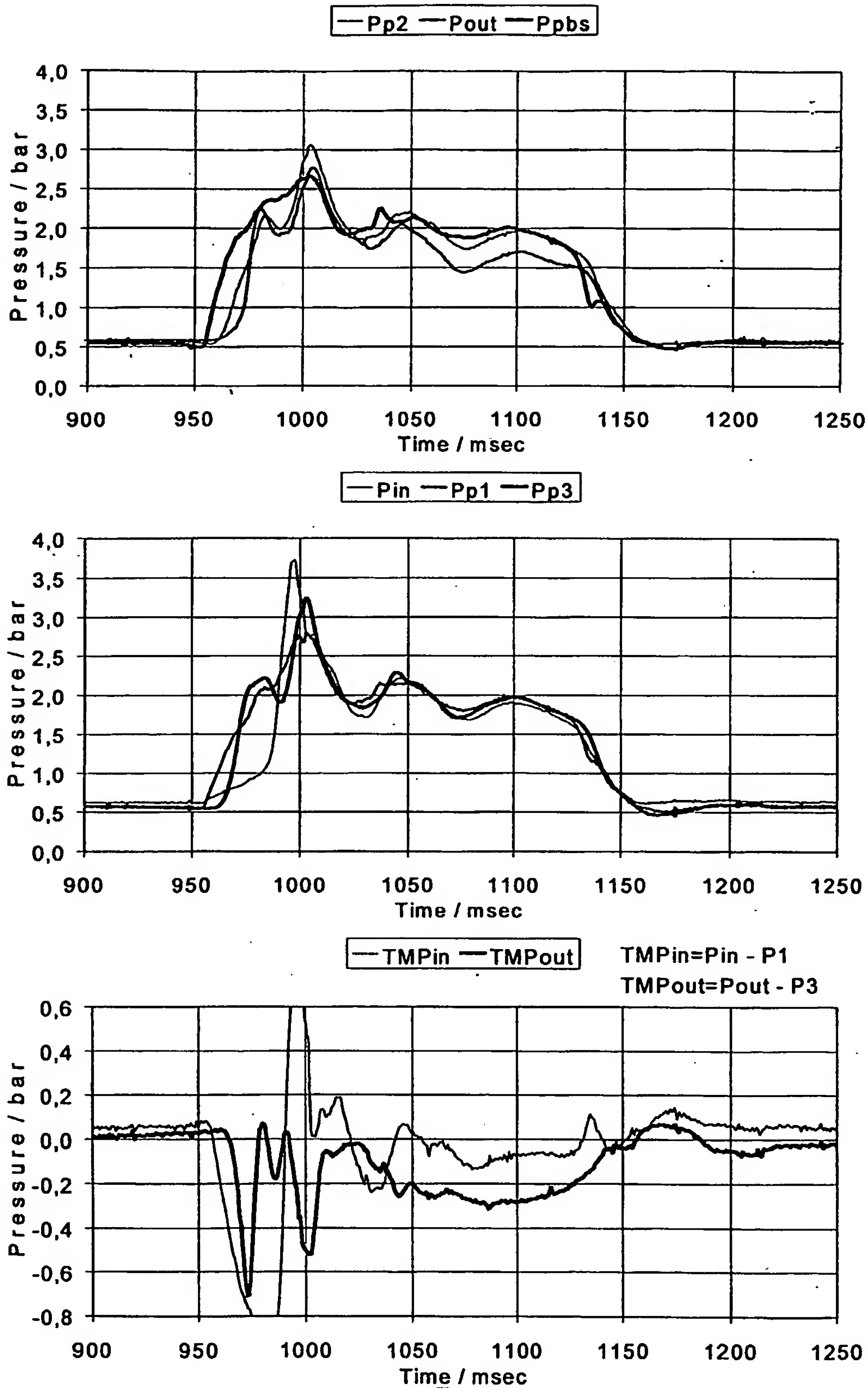

Feed
17
P_{Bbf}
P_{in}
3
21
23
6
P_{pbs}
P_{p1}
2a
2
1
P_2
P_3
5
26
Permeate
4
P_{out}
P_{Baf}
19
24
Retentate

Fig. 6



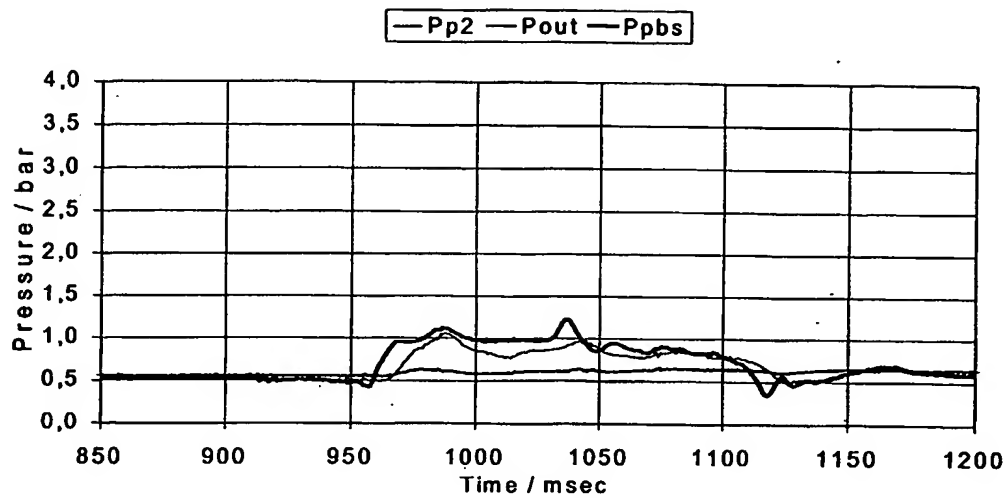
—Pp2 —Pout —Ppbs
Pressure / bar
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
850 900 950 1000 1050 1100 1150 1200
Time / msec
—Pin —Pp1 —Pp3
Pressure / bar
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
850 900 950 1000 1050 1100 1150 1200
Time / msec
—TMPin —TMPout
TMPin=Pin - P1
TMPout=Pout - P3
Pressure / bar
0,6
0,4
0,2
0,0
-0,2
-0,4
-0,6
-0,8
850 900 950 1000 1050 1100 1150 1200
Time / msec

Fig. 7

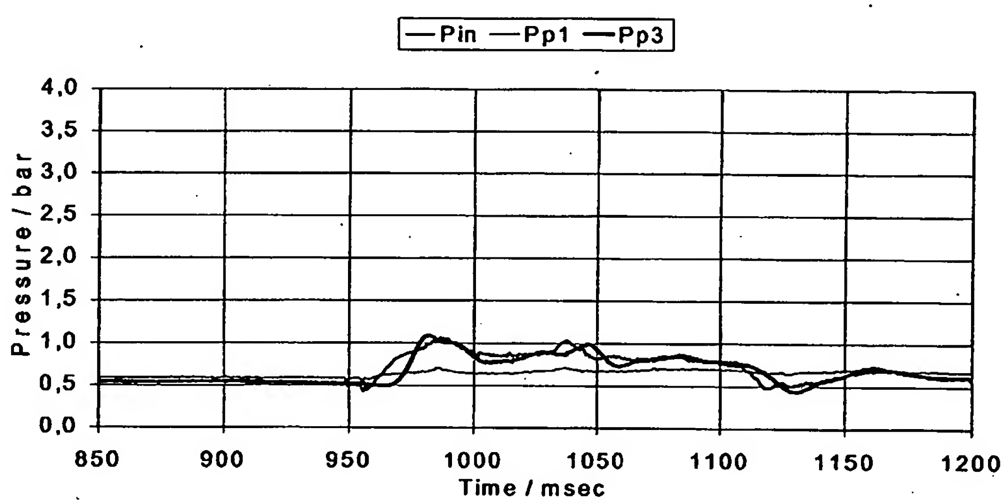


Pp2
Pout
Ppbs
Pressure / bar
Time / msec
Pin
Pp1
Pp3
Pressure / bar
Time / msec
TMPin
TMPout
TMPin=Pin - P1
TMPout=Pout - P3
Pressure / bar
Time / msec

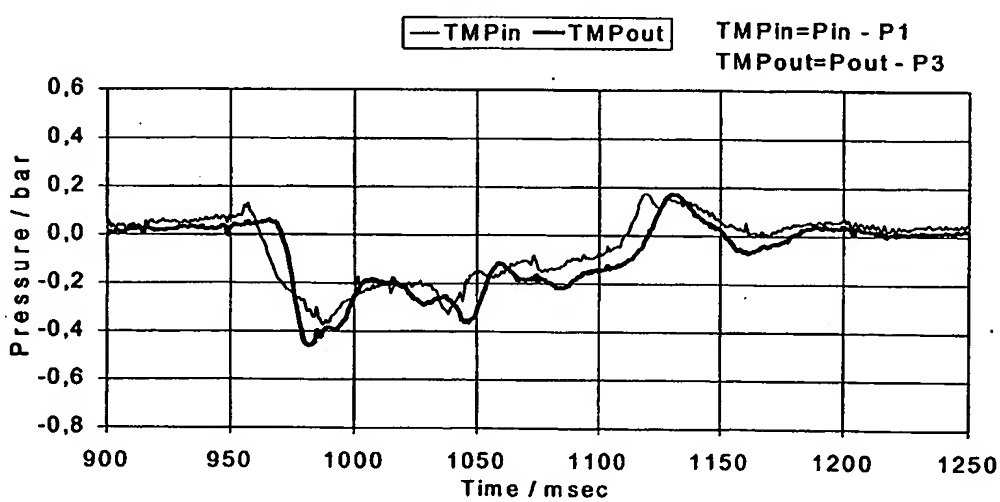
Fig. 8



—Pp2 —Pout —Ppbs
Pressure / bar
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
850
900
950
1000
1050
1100
1150
1200
Time / msec



—Pin —Pp1 —Pp3
Pressure / bar
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
850
900
950
1000
1050
1100
1150
1200
Time / msec



—TMPin —TMPout
TMPin=Pin - P1
TMPout=Pout - P3
Pressure / bar
0,6
0,4
0,2
0,0
-0,2
-0,4
-0,6
-0,8
900
950
1000
1050
1100
1150
1200
1250
Time / msec

Fig. 9

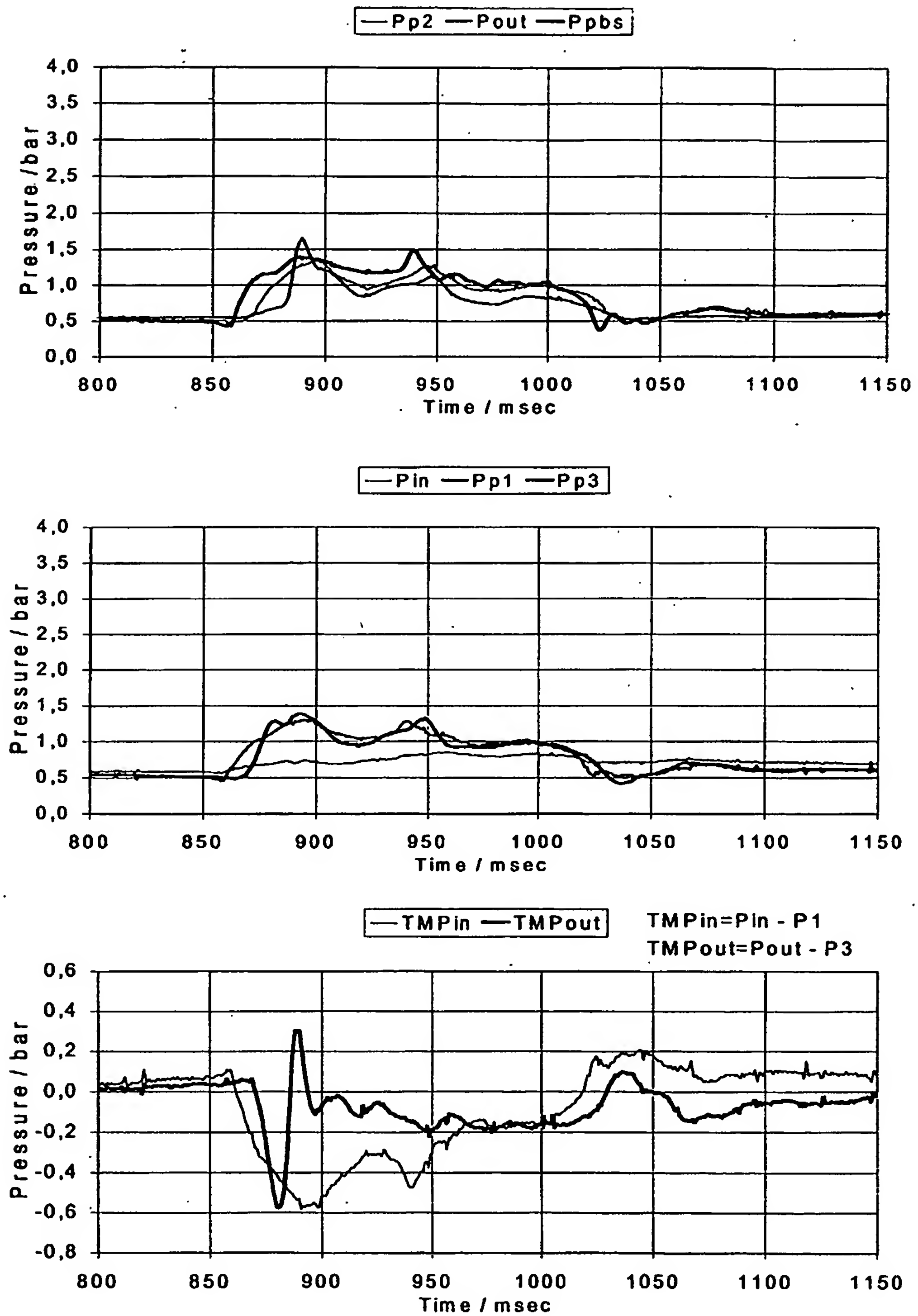
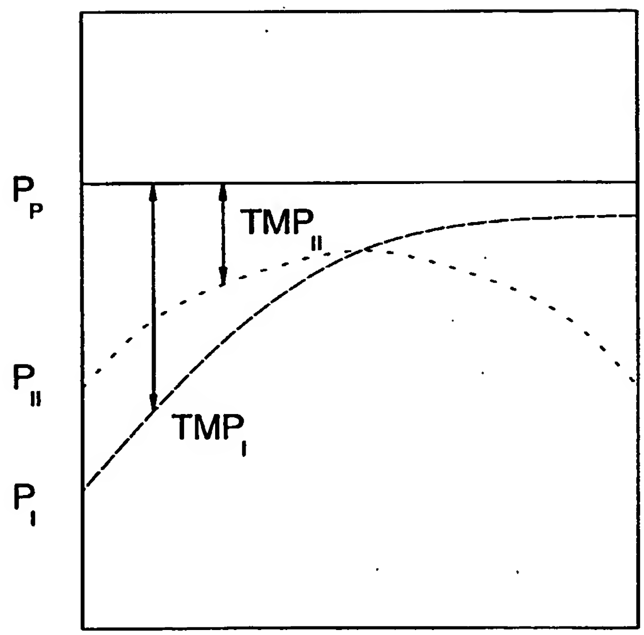

Pp2
Pout
Ppbs
Pressure /bar
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
800
850
900
950
1000
1050
1100
1150
Time / msec
Pin
Pp1
Pp3
Pressure / bar
Time / msec
TMPin
TMPout
TMPin=Pin - P1
TMPout=Pout - P3
0,6
0,4
0,2
0,0
-0,2
-0,4
-0,6
-0,8
Pressure / bar
Time / msec

Fig. 10



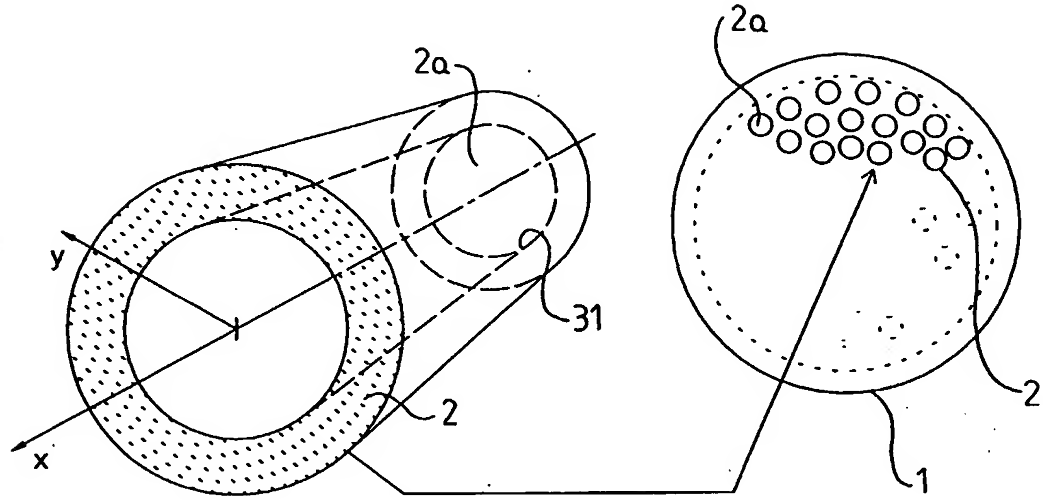


Fig. 11

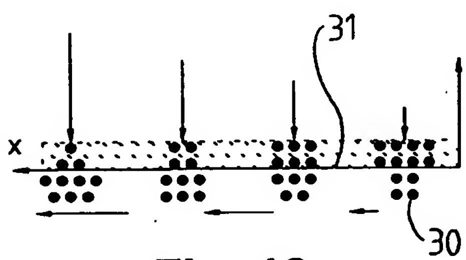


Fig. 12

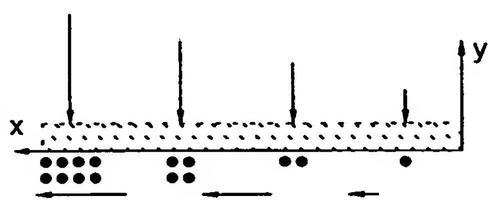


Fig. 13

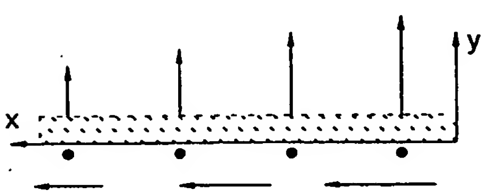


Fig. 14

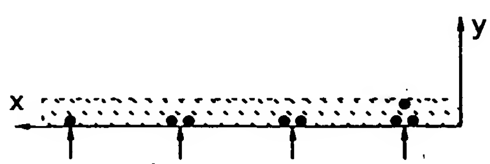


Fig. 15

Fig. 16

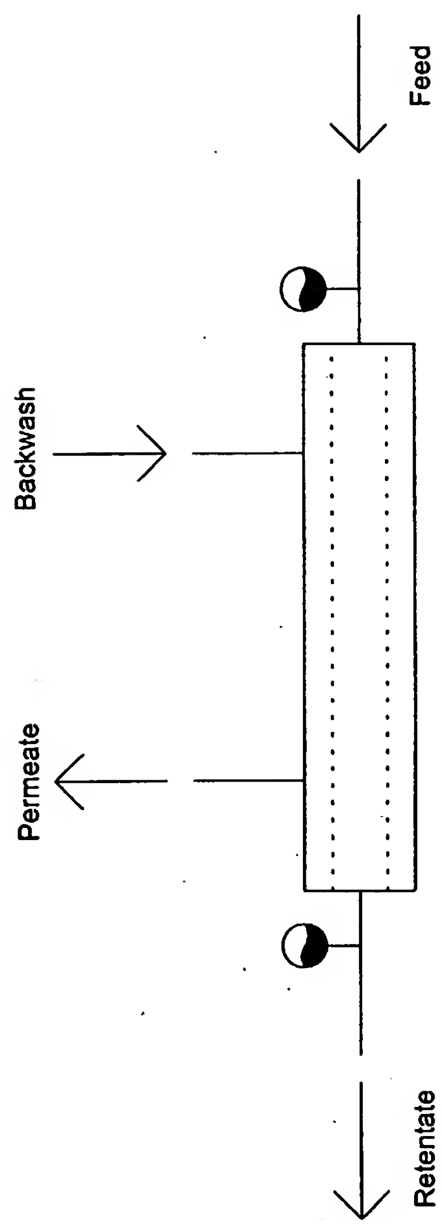


Fig. 17

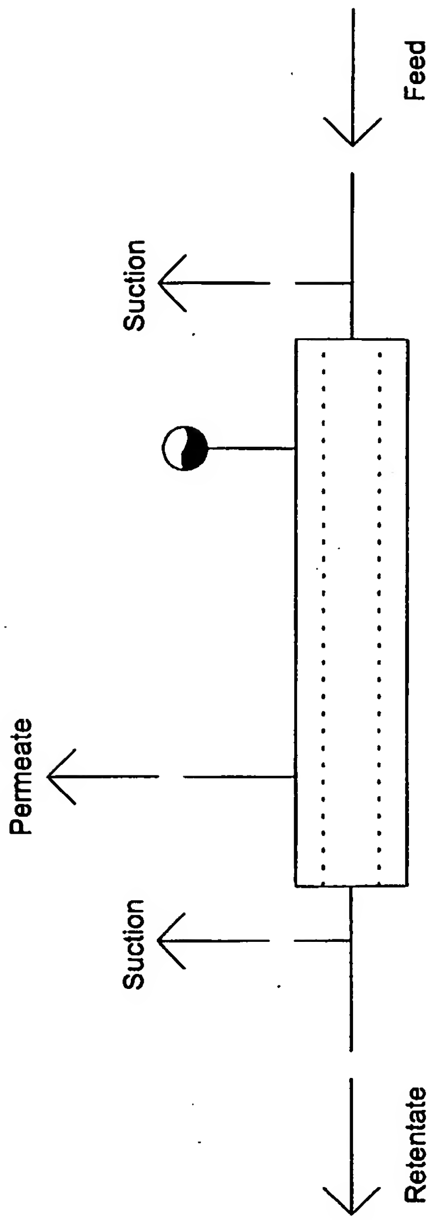


Fig. 18

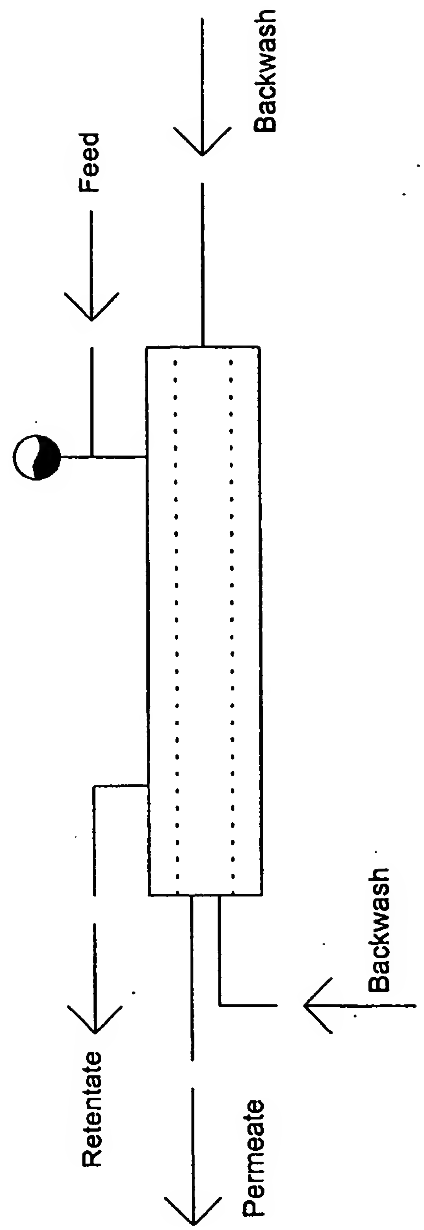


Fig. 19

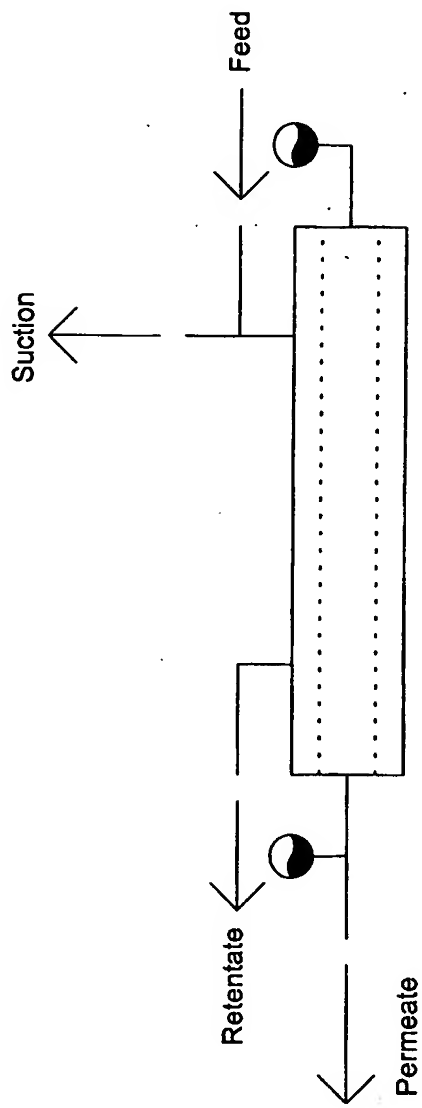


Fig. 20

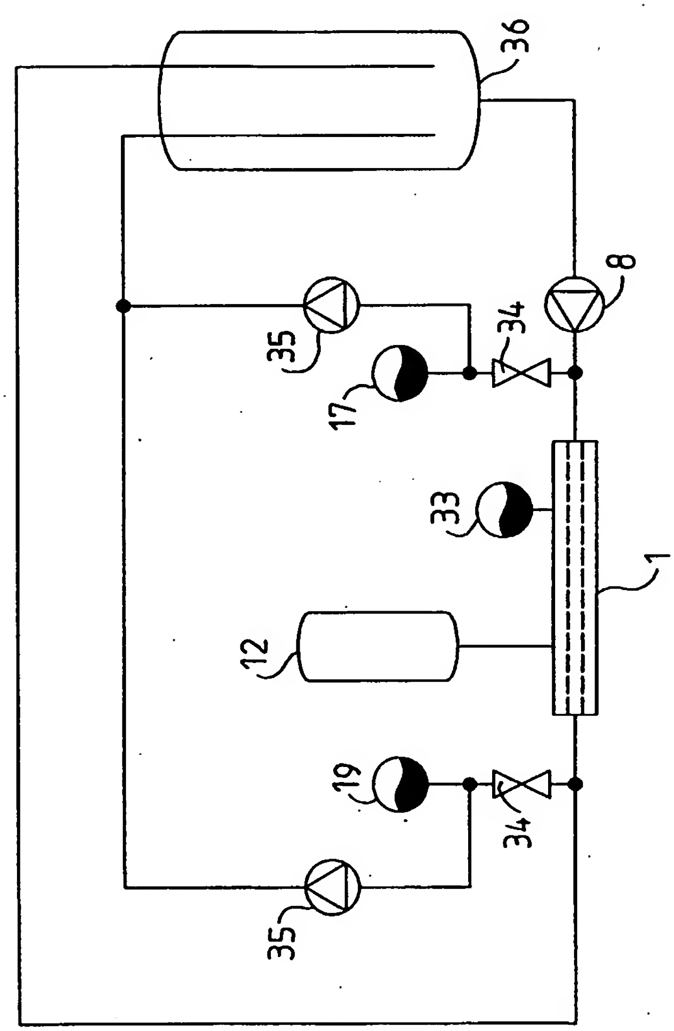


Fig. 21

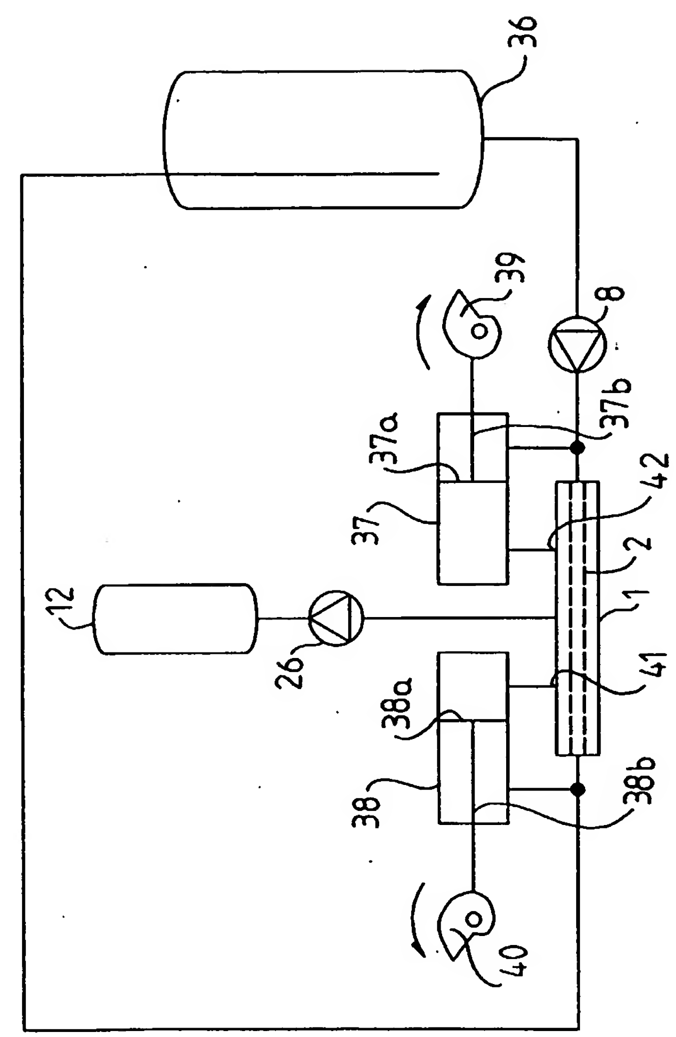


Fig. 22

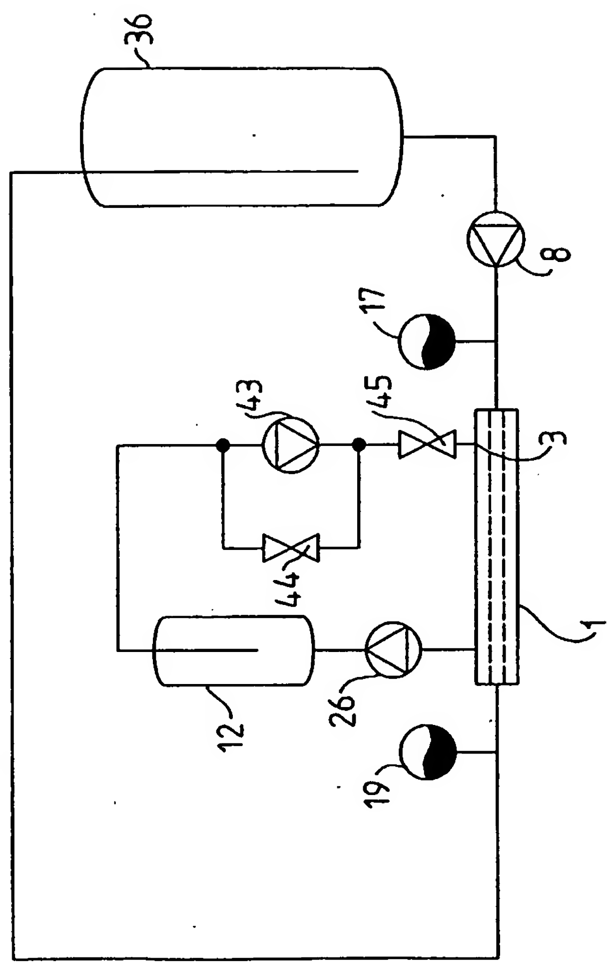


Fig. 23

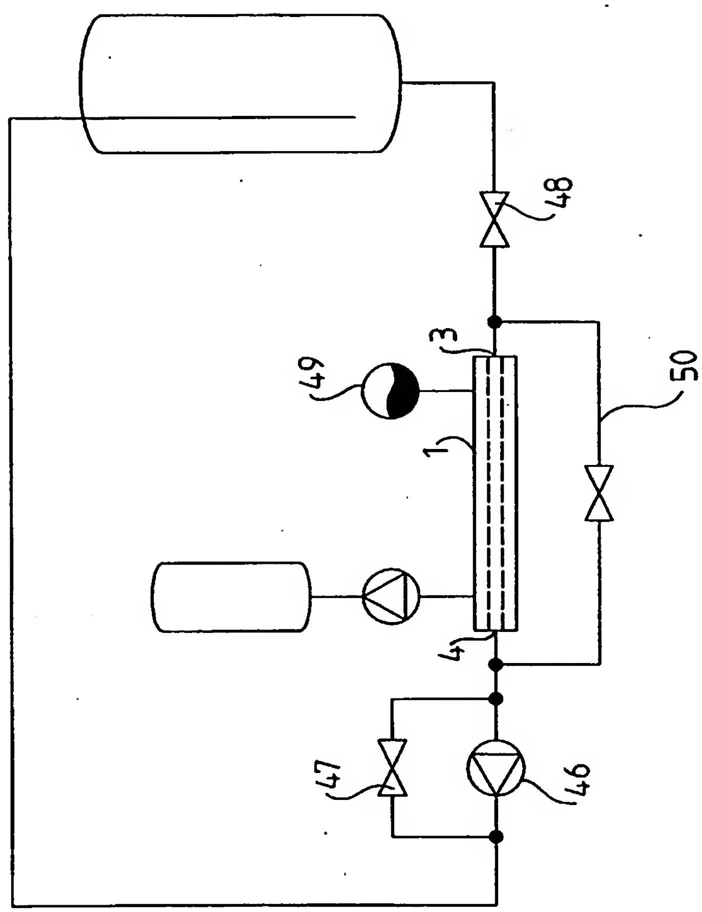


Fig. 24

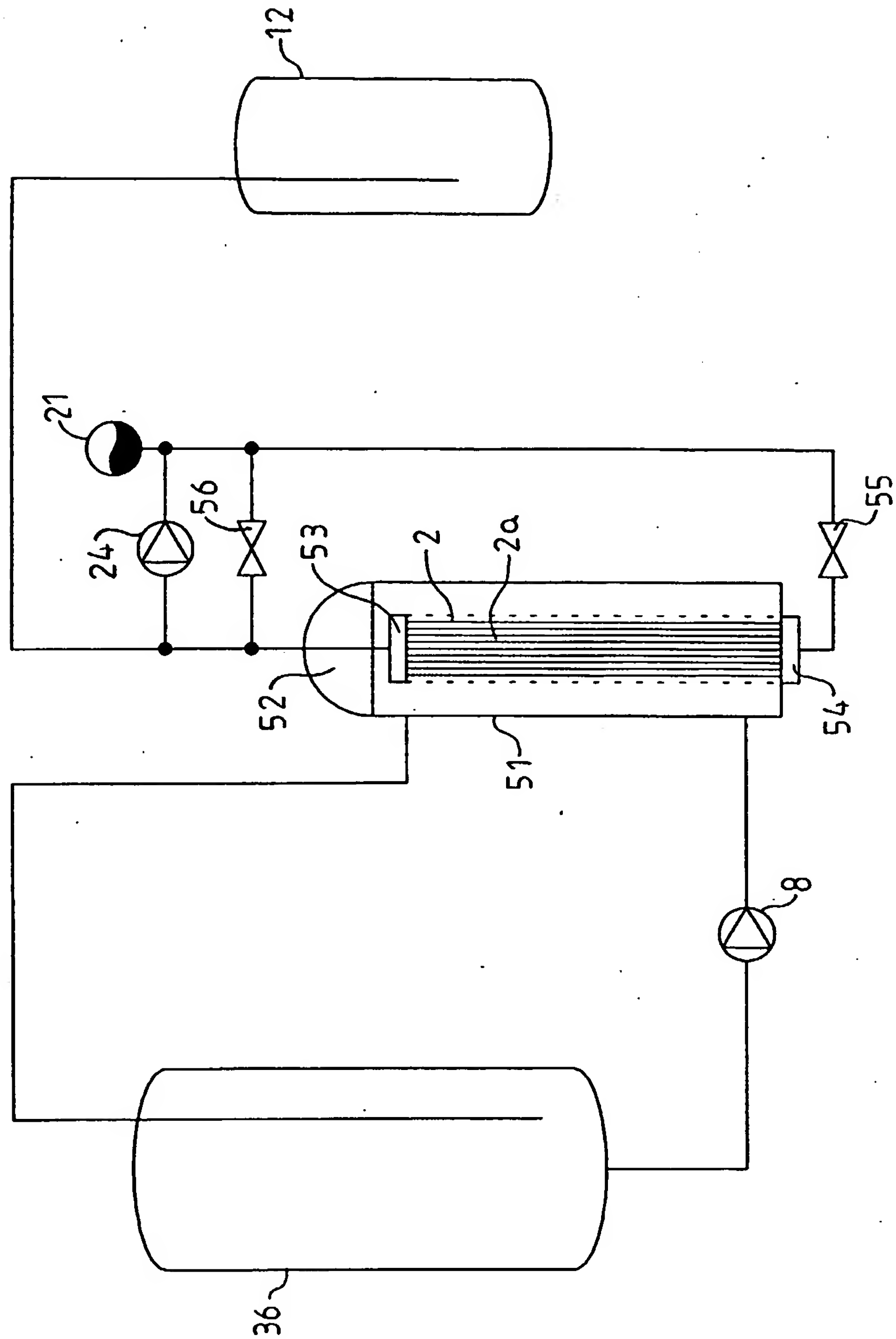


Fig. 25

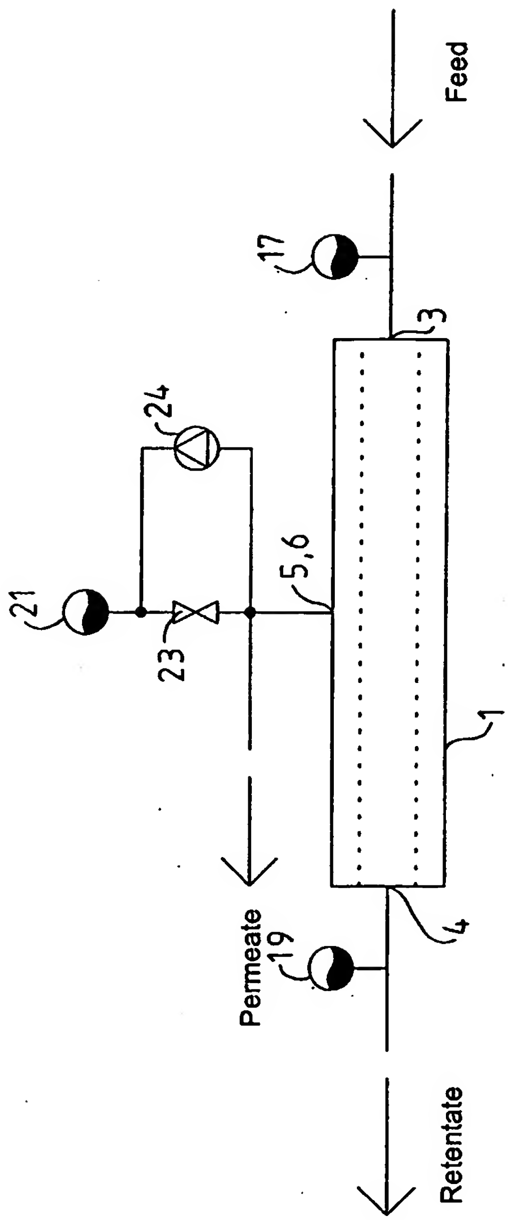


Fig. 26

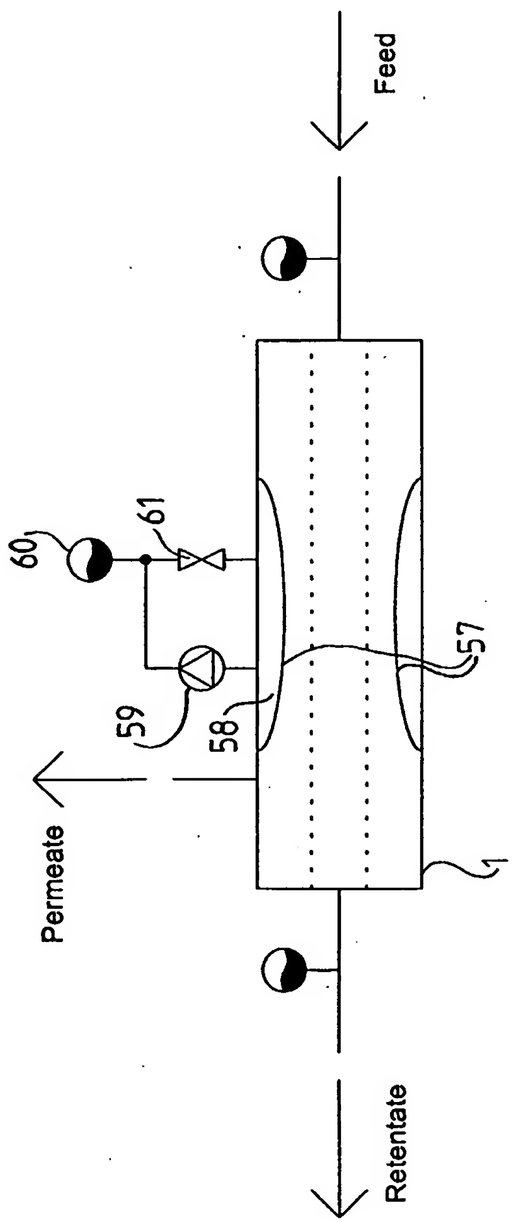


Fig. 27

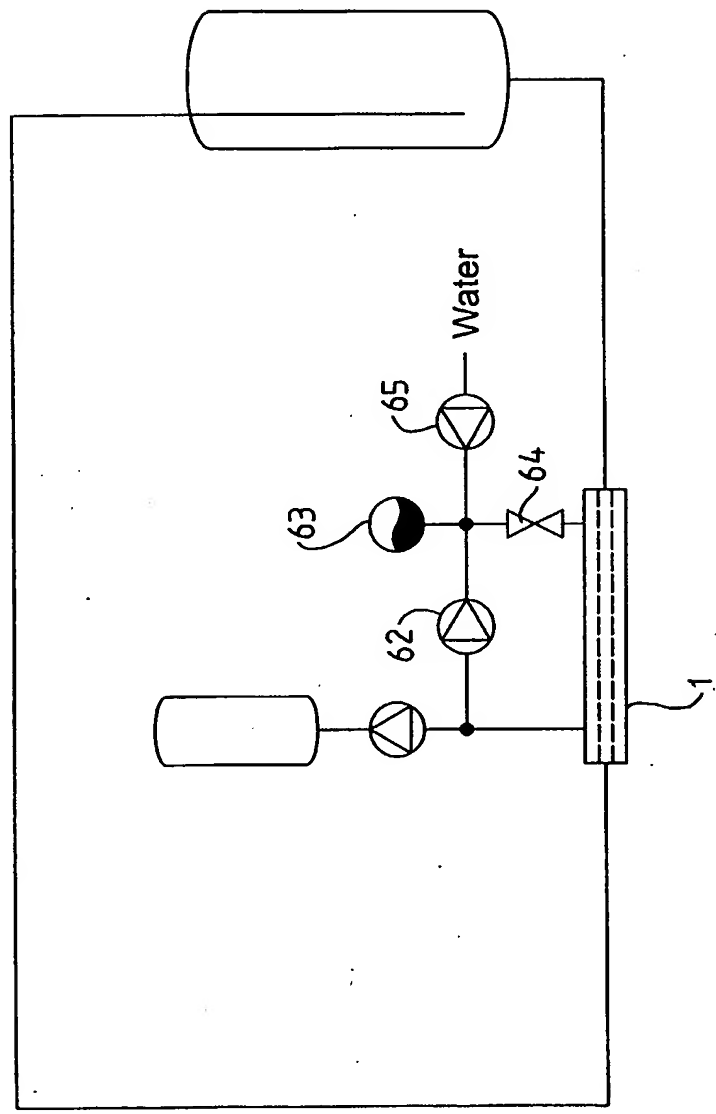


Fig. 28

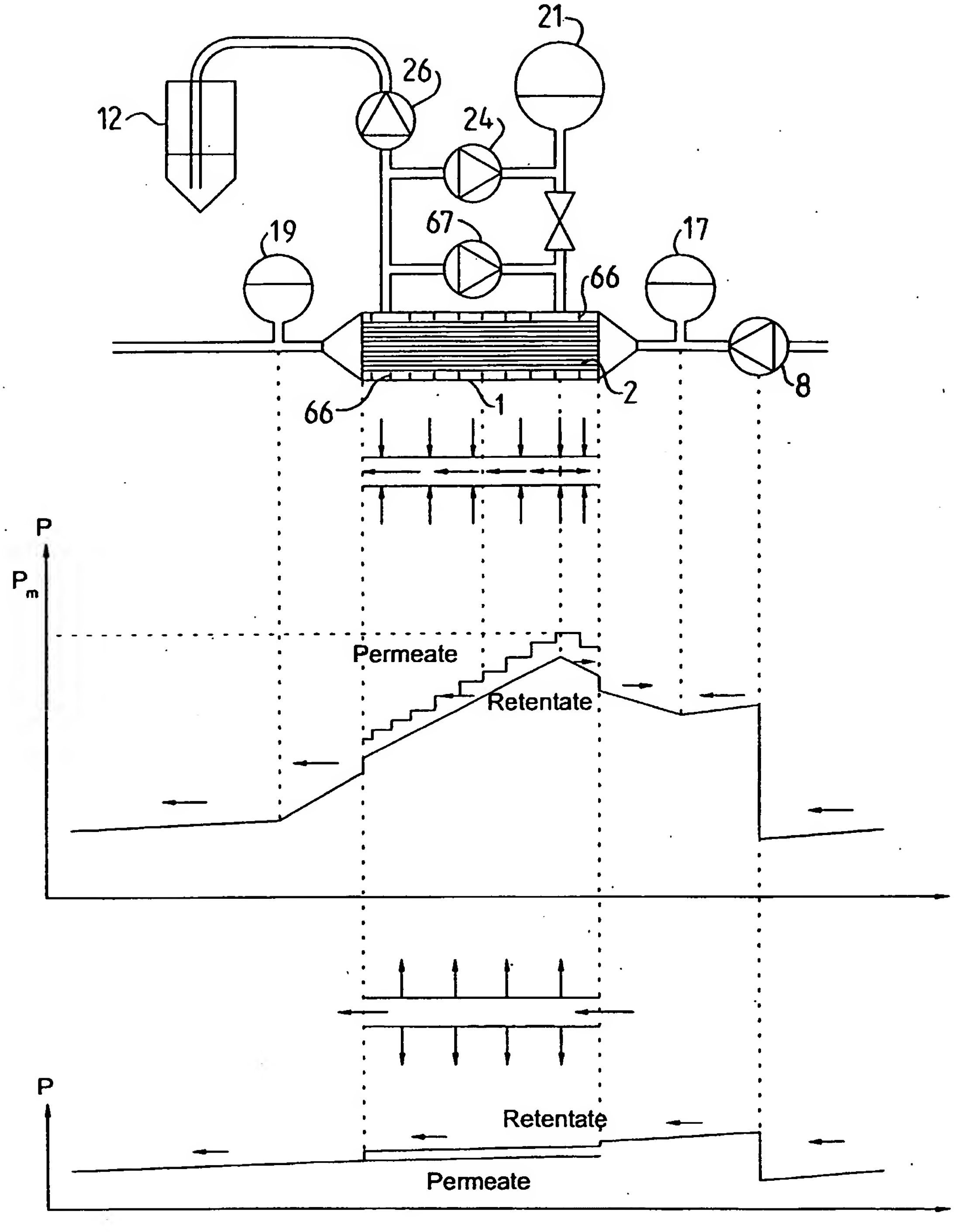

21
26
24
12
67
19
17
66
66
1
2
8
P
P_m
Permeate
Retentate
P
Retentate
Permeate

Fig. 29

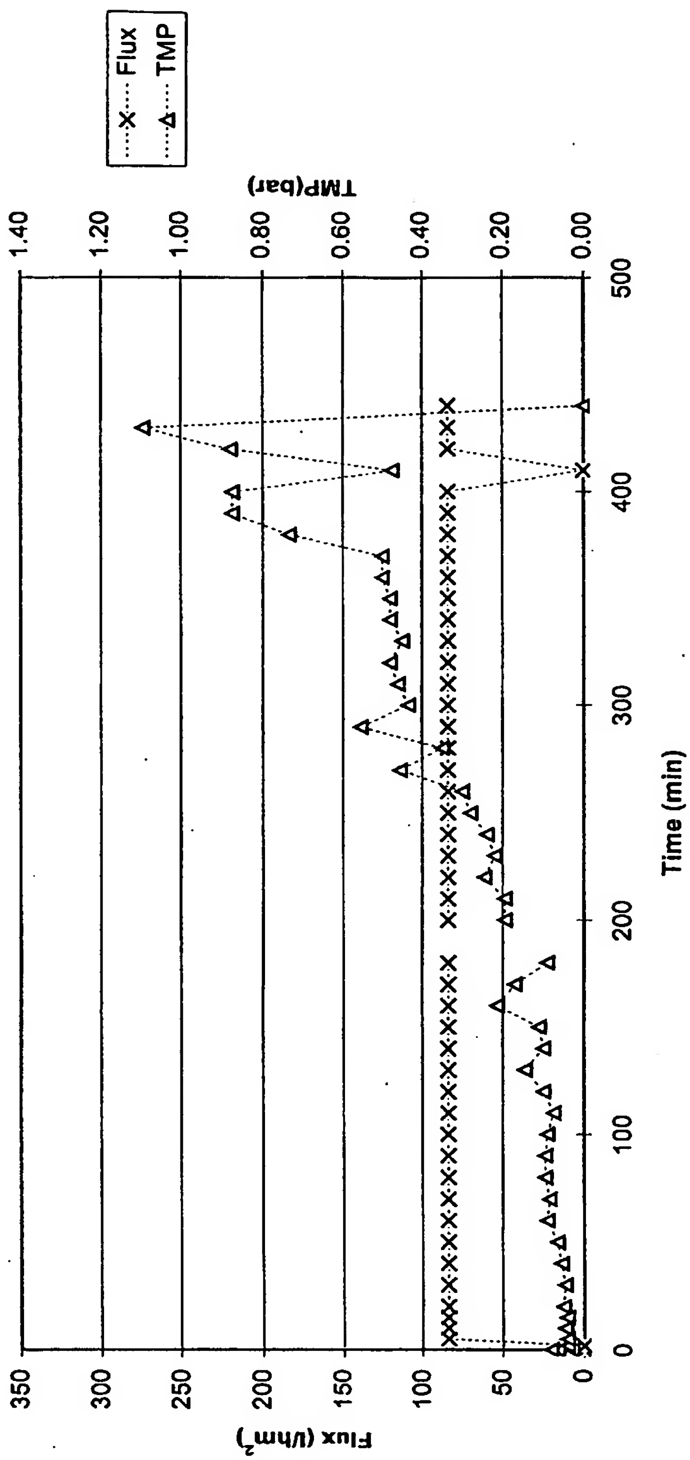
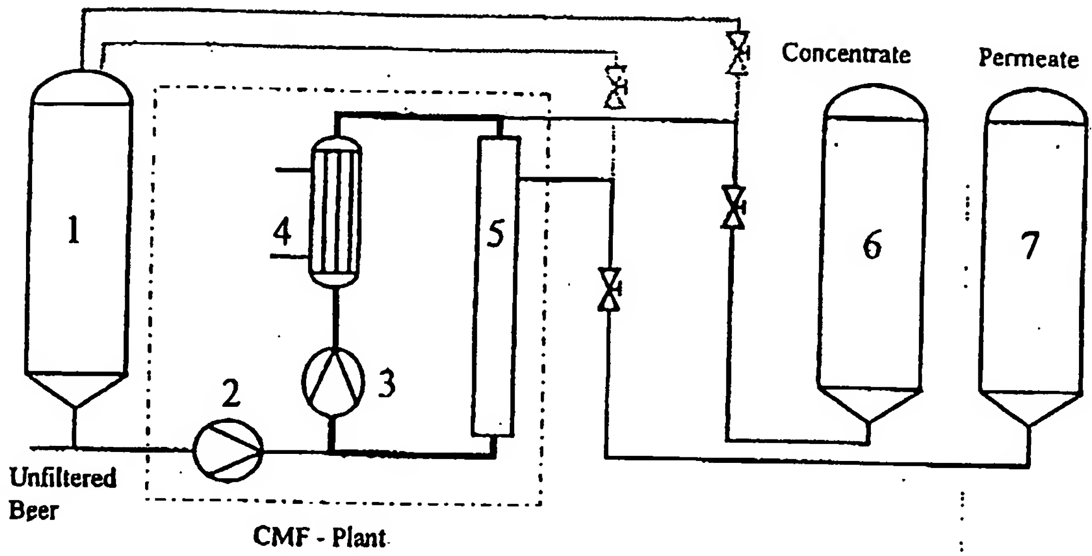


Fig. 30



1 - buffer tank; 2 - feed pump; 3 - recirculation pump; 4 - cooler; 5 - module; 6- concentrate tank; 7 - permeate tank

Laboratory- and Pilot System-Set Up. used by Schenk Filterbau GmbH for beer filtration (ref. MBAA District Carribbean, 34 Annual Conventio 4/95).

Fig. 31

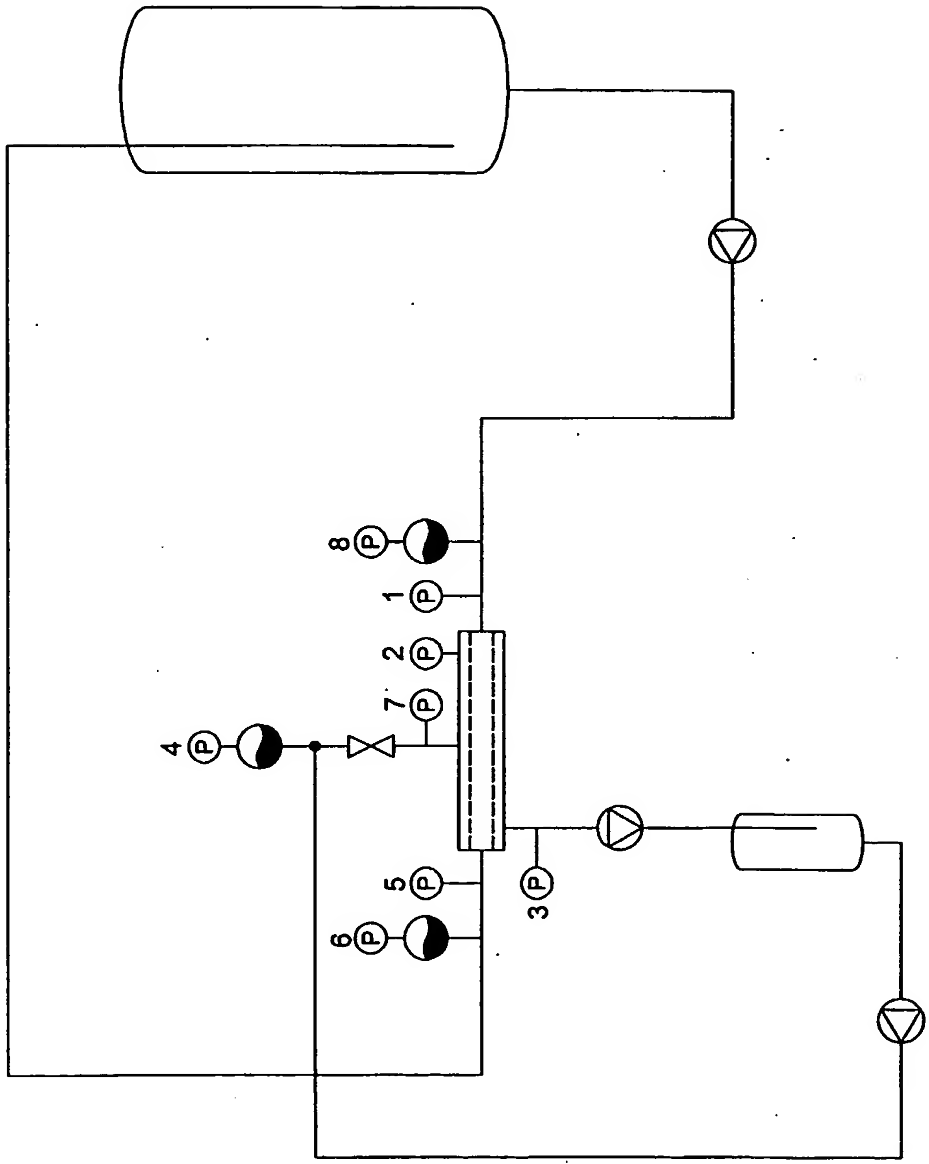


Fig. 32

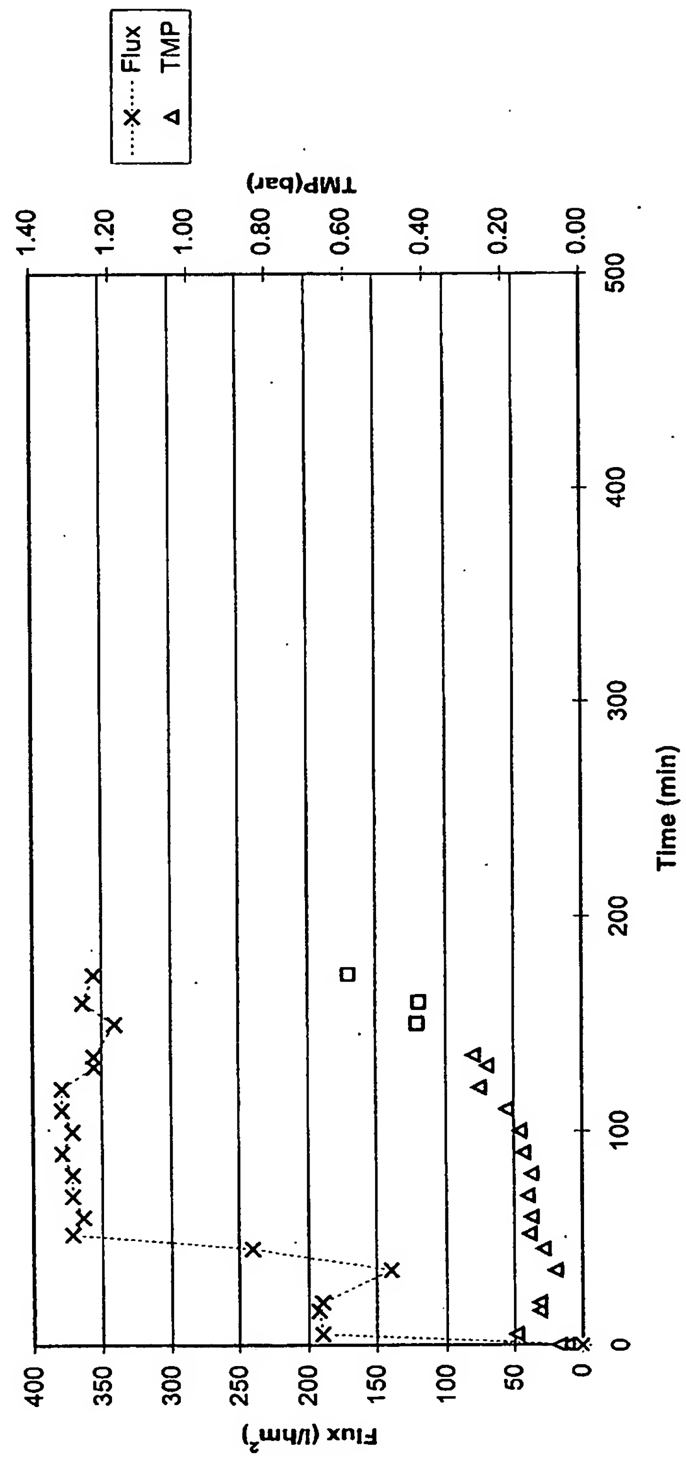
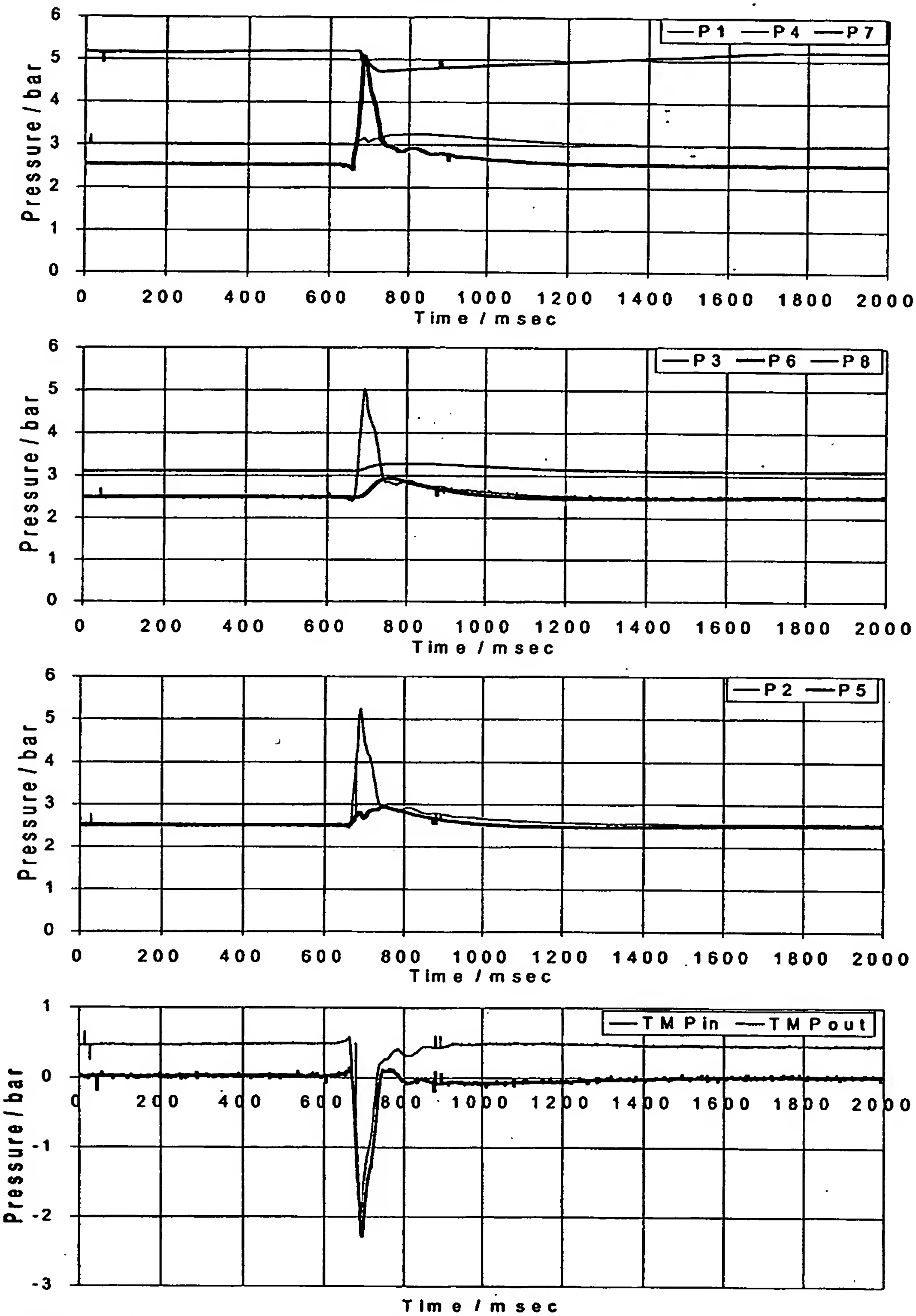


Fig. 33



TMPin=P1 - P2 TMPout=P5 - P3

Fig. 34

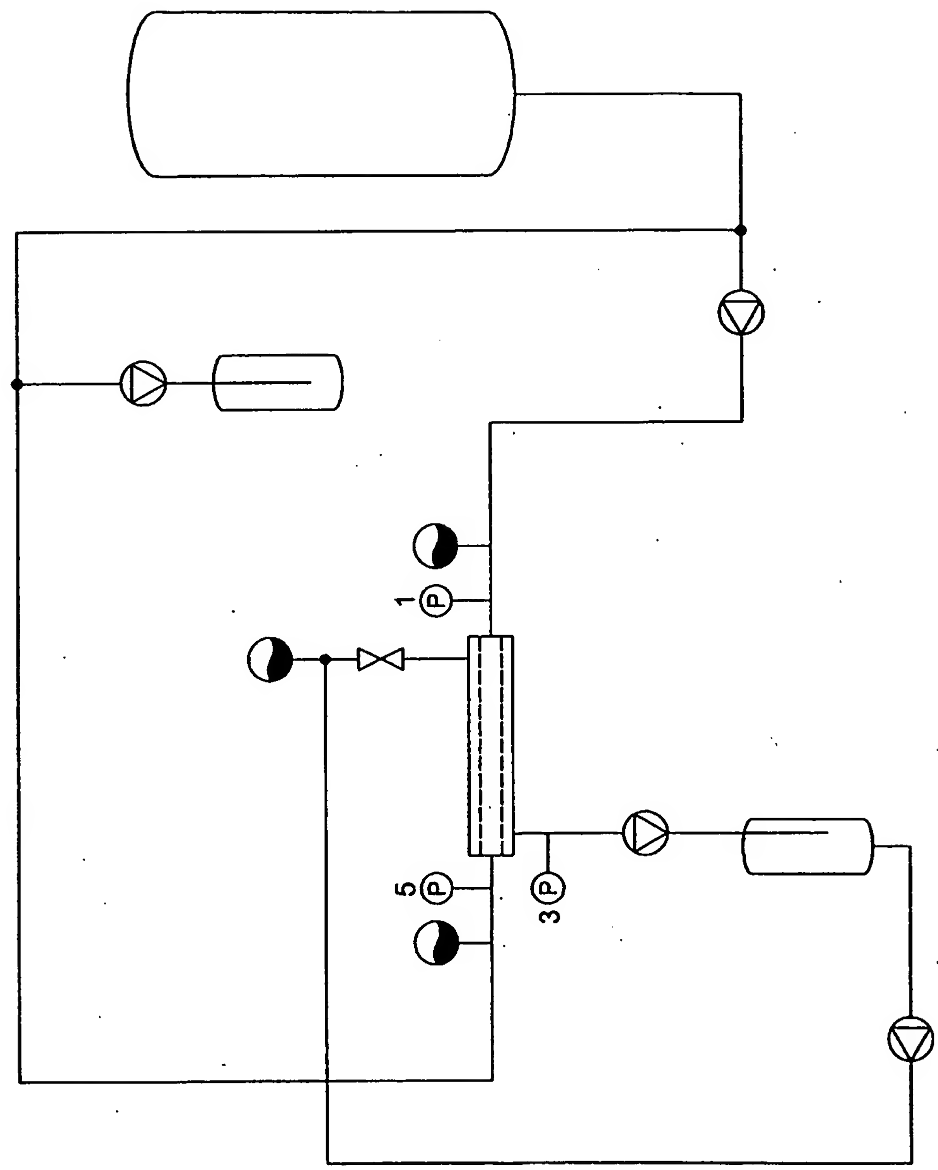


Fig. 35

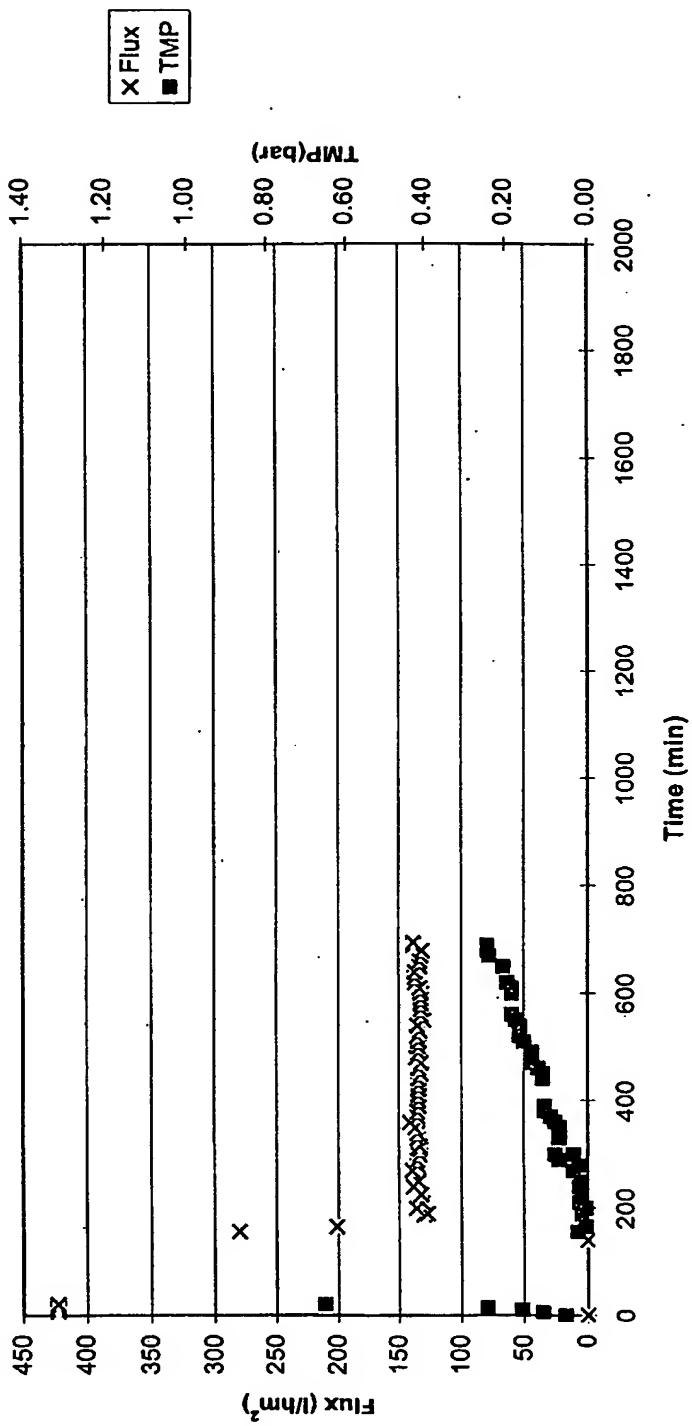


Fig. 36

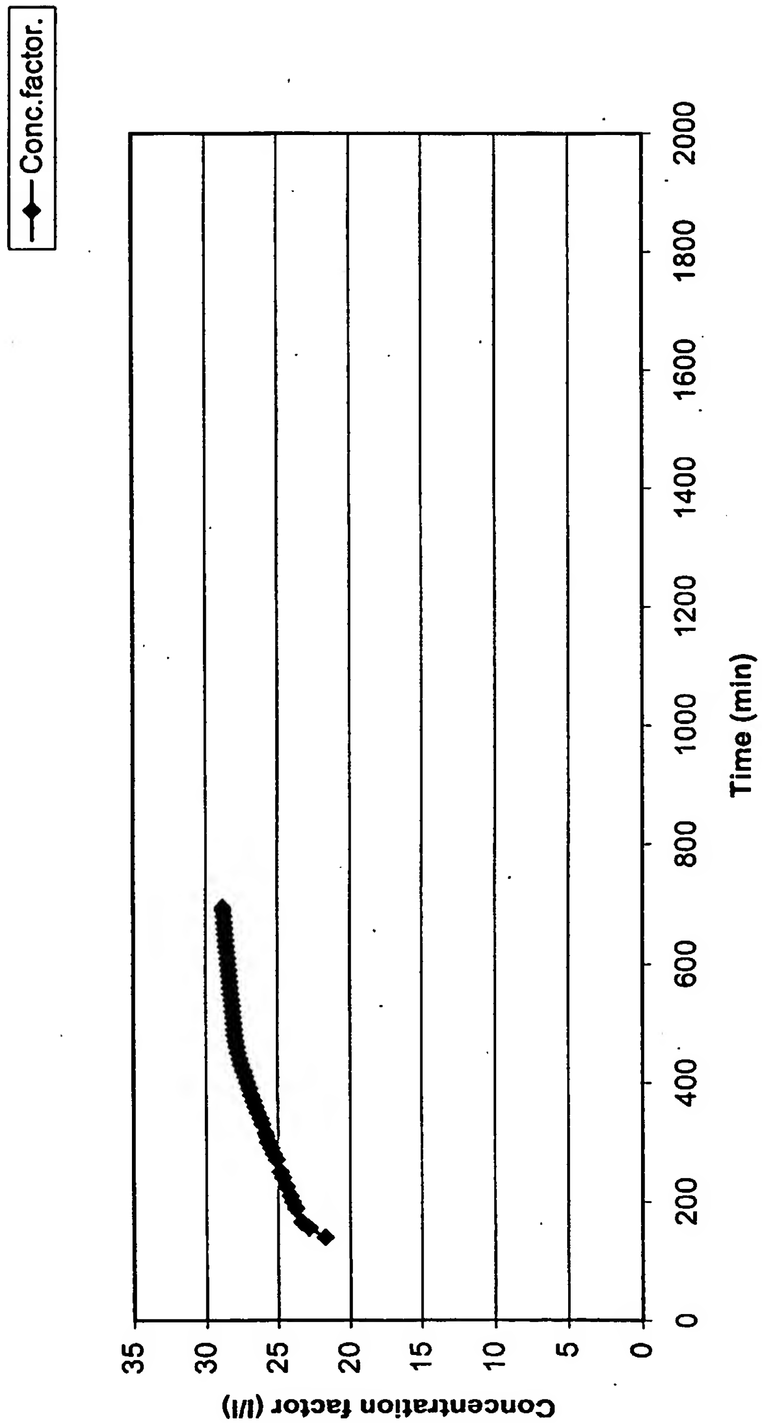
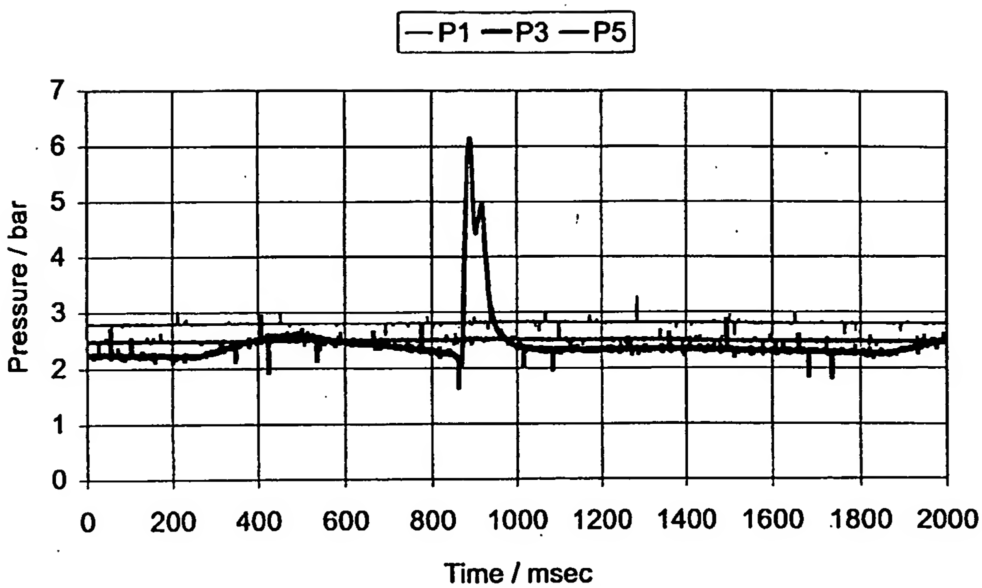
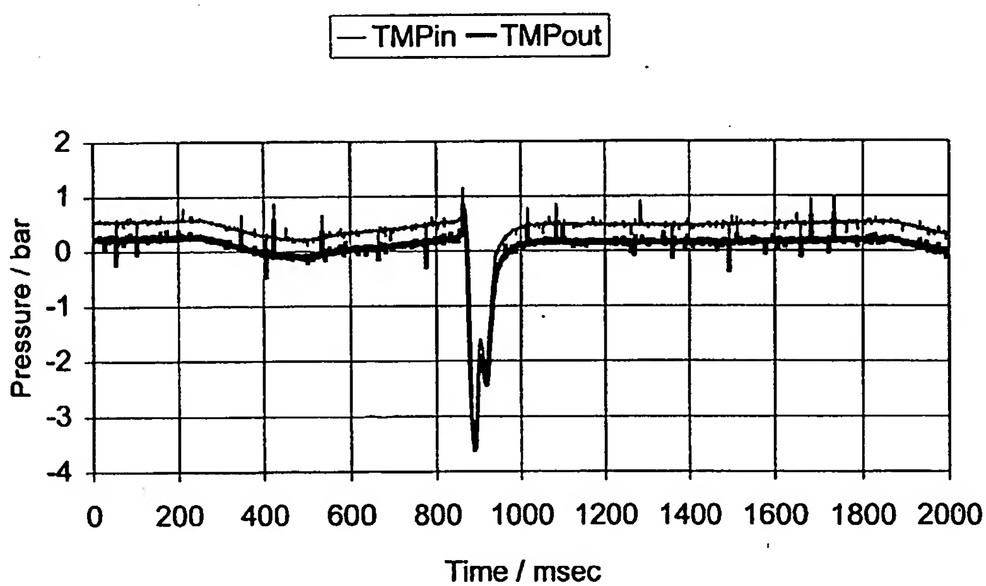

Conc.factor.
Concentration factor (l/l)
0
5
10
15
20
25
30
35
Time (min)
0
200
400
600
800
1000
1200
1400
1600
1800
2000

Fig. 37



—P1 —P3 —P5
Pressure / bar
7
6
5
4
3
2
1
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Time / msec



—TMPin —TMPout
Pressure / bar
2
1
0
-1
-2
-3
-4
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Time / msec

Fig. 38

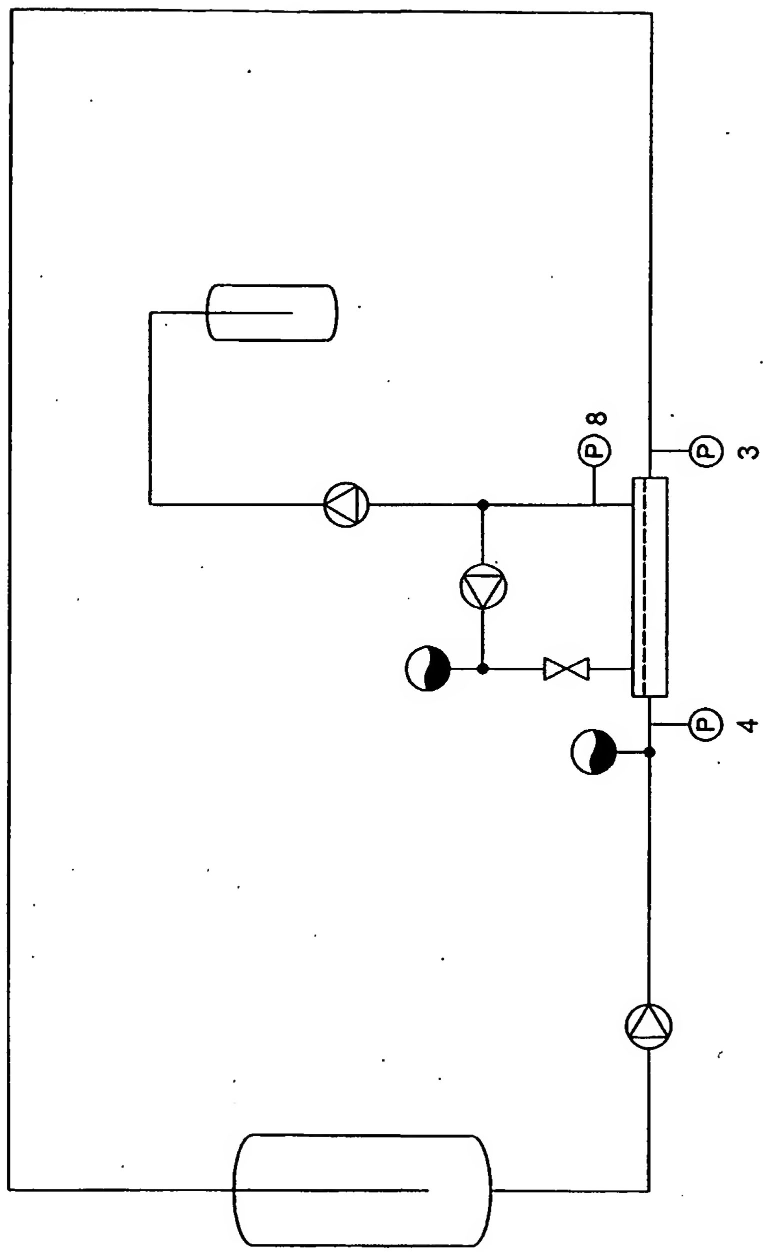


Fig. 39

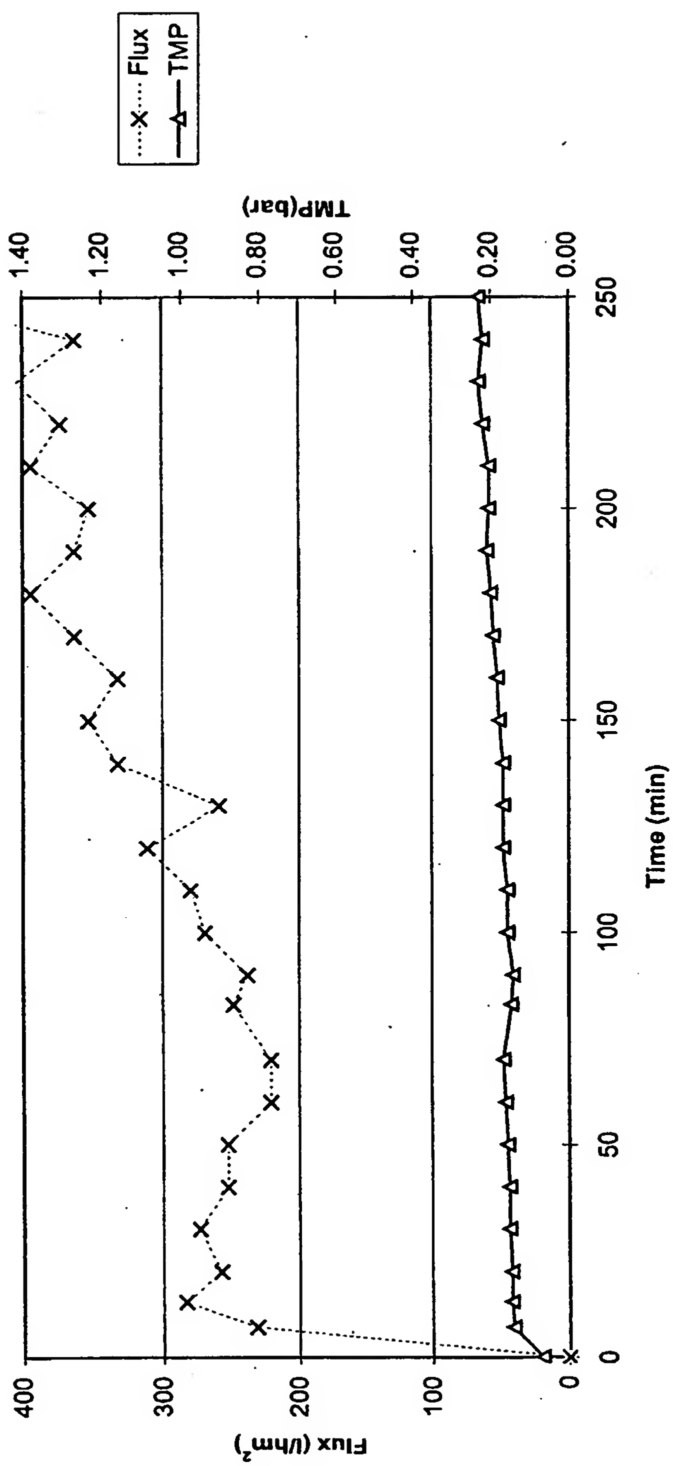
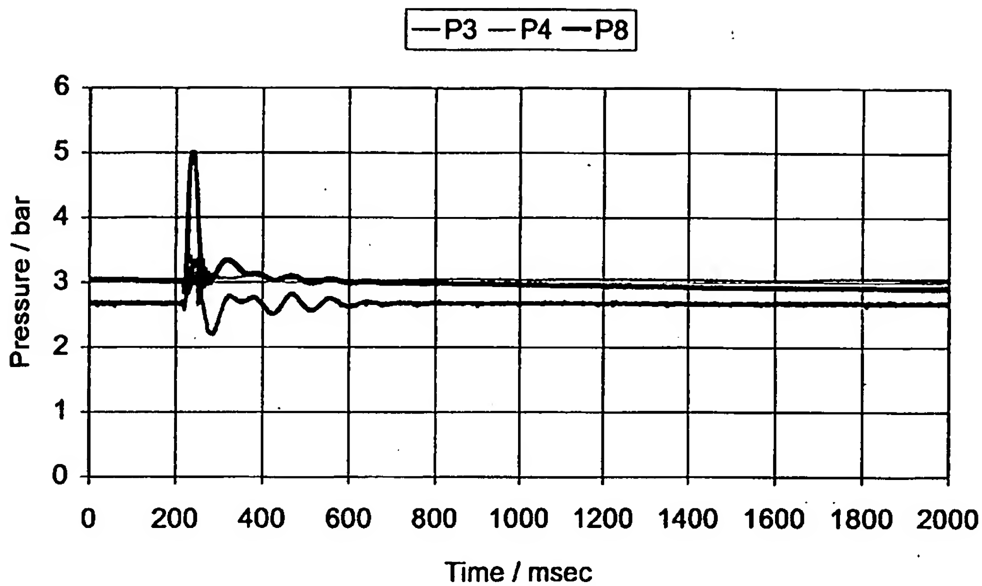
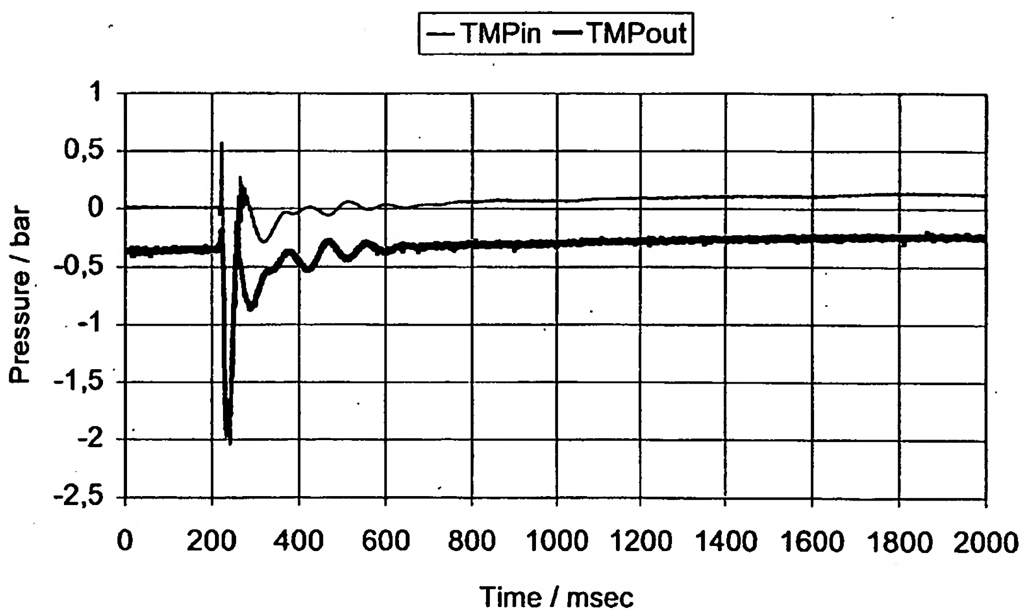


Fig. 40





TMPin=P4 - P8 TMPout=P3 - P8

Fig. 41

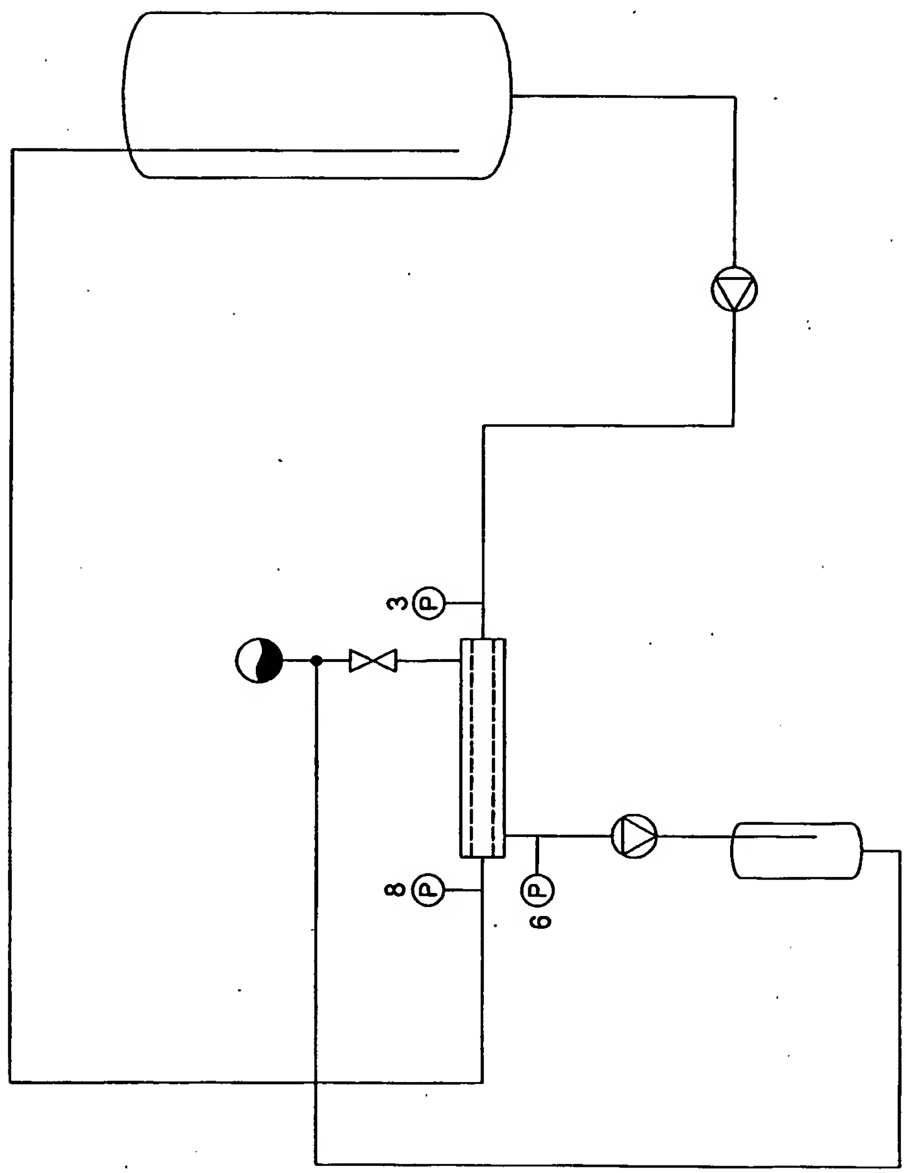
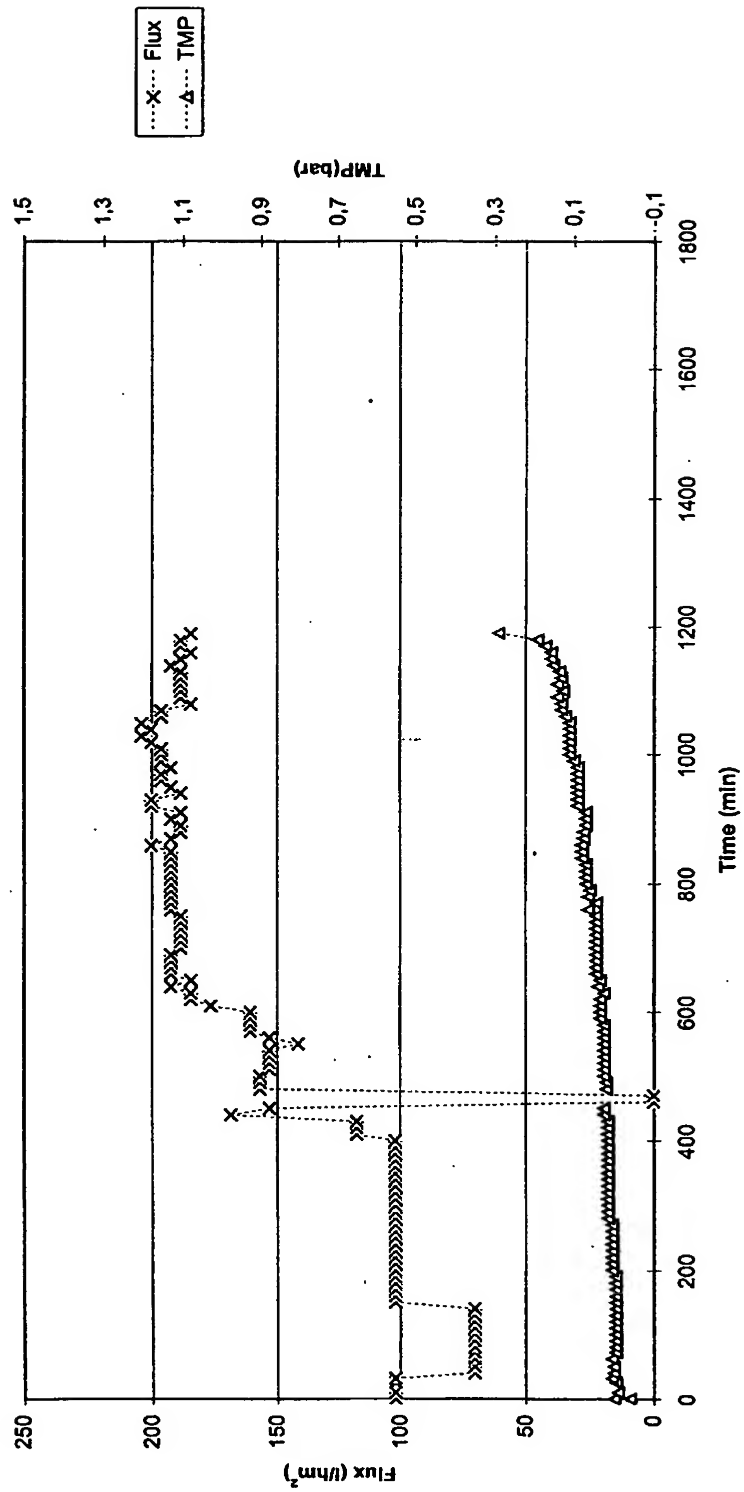
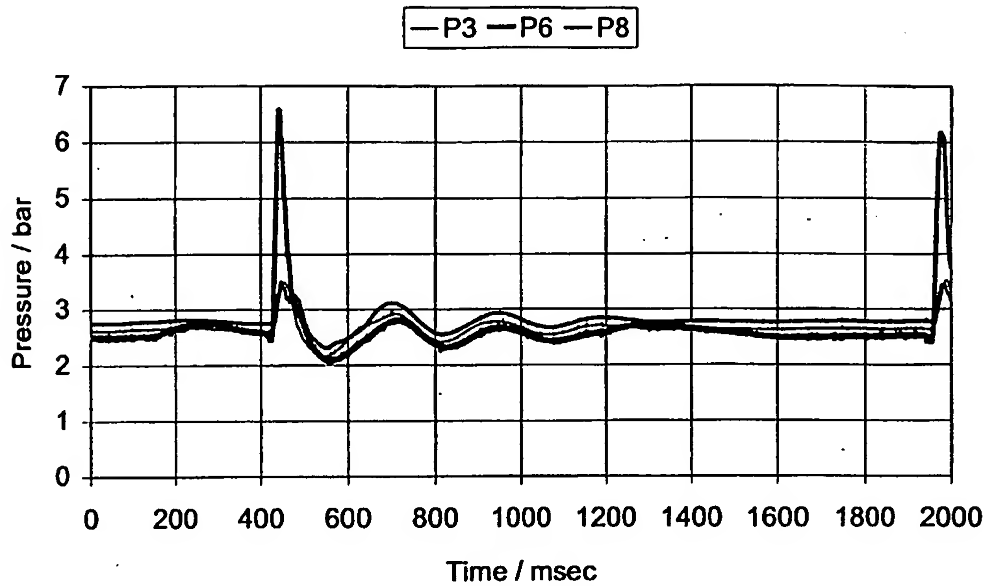


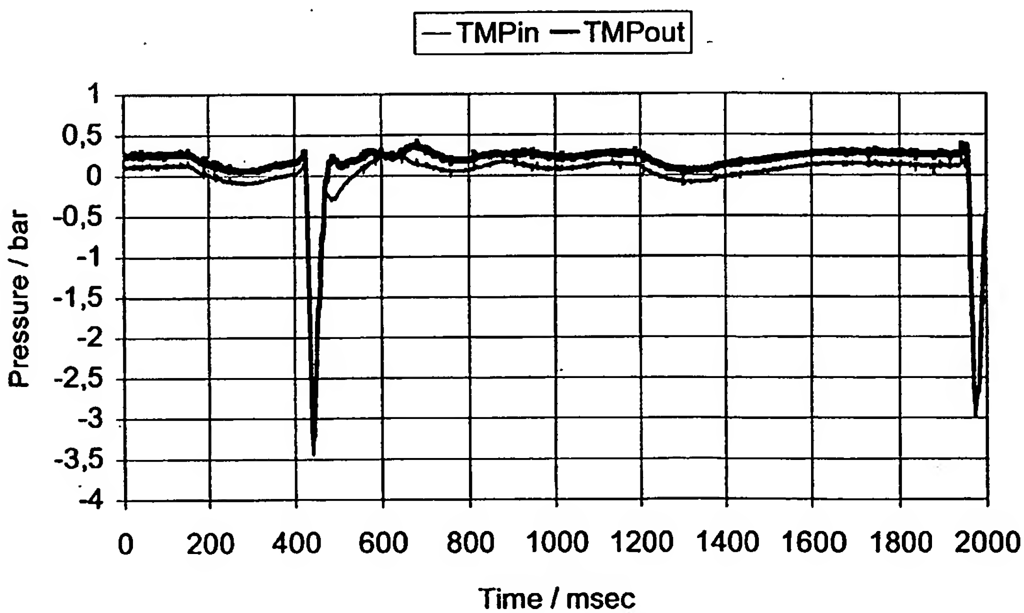
Fig. 42



Flux
TMP
TMP(bar)
1,5
1,3
1,1
0,9
0,7
0,5
0,3
0,1
-0,1
Flux (l/hm²)
250
200
150
100
50
0
Time (min)
0
200
400
600
800
1000
1200
1400
1600
1800

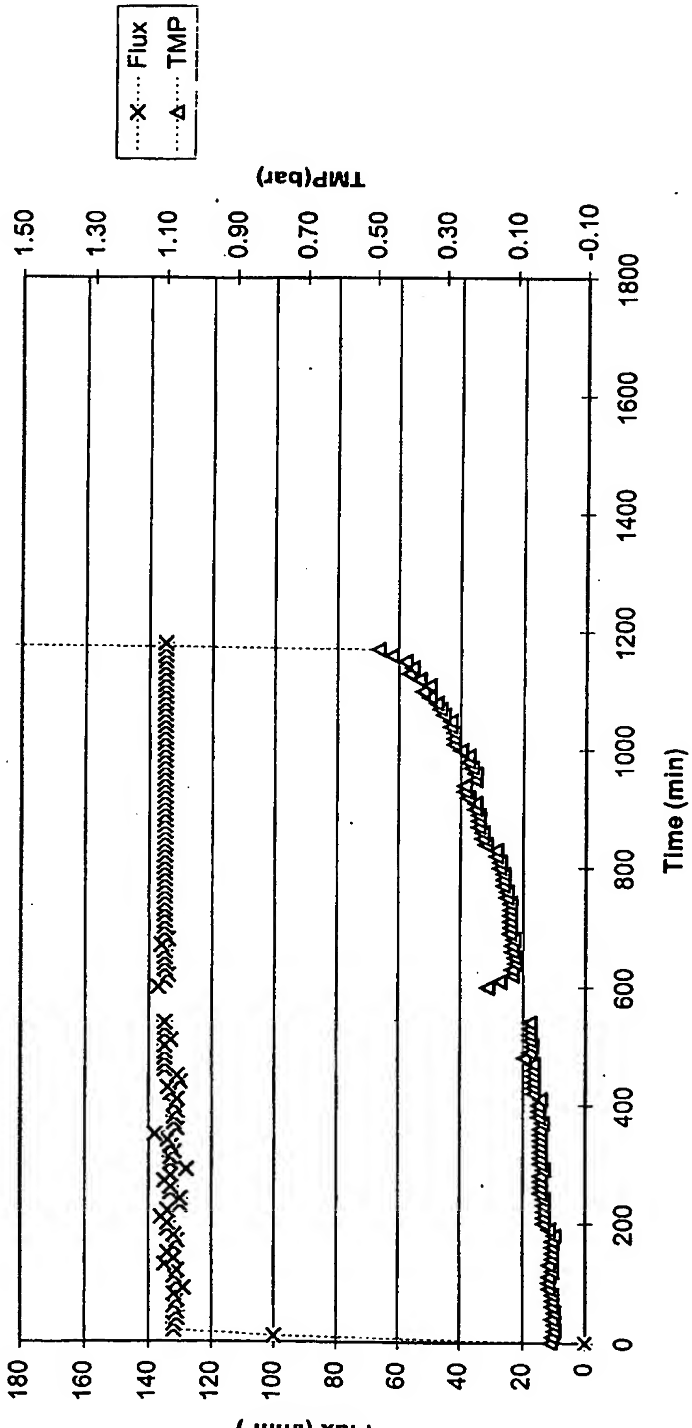
Fig. 43





TMPin=P3 - P6 TMPout=P8 - P6

Fig. 44


Flux
TMP
TMP(bar)
1.50
1.30
1.10
0.90
0.70
0.50
0.30
0.10
-0.10
Time (min)
0
200
400
600
800
1000
1200
1400
1600
1800
Flux (l/hm²)
180
160
140
120
100
80
60
40
20
0